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PROJECT SECEDE

LOBE SWEEP INTERFEROMETERS FOR SECEDE II

Northwest Environmental Technology Laboratories, Incorp.

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13. ABSTRACT

Two pairs of twin-element, lobe-sweep radio interferometers have been designed, constructed and bench-tested for the SECEDE II transmission experiments. One pair operates at a frequency of 145.7644 MHz, the other at 437.2932 MHz. The total of four interferometers are realized with three circularly polarized, broadband log-periodic antennas spaced equally along a two hundred meter baseline with the center antenna common to each interferometer pair. Recorded interferometer outputs at each frequency include (1) a quasi-logarithmic signal amplitude from each antenna; (2) two phase difference measurements between antenna pairs of each interferometer, one direct and the other shifted in phase by π radians; and (3) a differential phase measurement, i.e., the difference between the individual interferomenter phase difference measurements. Generalized block diagrams of the interferometer systems are presented, as are the results of the bench tests of system performance.

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PROJECT SECEDE
LOBE SWEEP INTERFEROMETERS FOR SECEDE II

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FORWARD

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I. INTRODUCTION

The SECEDE II transmission experiment review committee, 6 December 1969, has recommended that interferometer measurements be implemented in the SECEDE II RF beacon ground measurements. Analysis of the interferometer data will indicate the relative importance of diffraction in the interpretation of the ionospheric model associated with a Barium release. The results of the interferometer observations are expected to define limitations due to fine scale structure in the determination of ionospheric structure by direct interpretation of the differential Doppler data.

This interim report has been prepared to describe the basic interferometer design and to report the results of the bench acceptance tests.

II. DESCRIPTION OF THE EQUIPMENT

A. GENERAL

Two pairs of twin-element, lobe-sweep radio interferometers have been designed for the SECEDE II transmission experiments. One pair operates at a frequency of 145.7644 MHz, the other at 437.2932 MHz. The total of four interferometers are realized with three circularly polarized, broadband log-periodic antennas spaced equally along a two hundred meter baseline, with the center antenna common to each interferometer pair.

The interferometer outputs at each frequency consist of the following:

1. A quasi-logarithmic amplitude output is obtained from each antenna. This output is referred to as log i, where i denotes the antenna referenced.
2. Two measures of the phase difference between antenna pairs of each interferometer are provided, one direct, the other shifted in phase by π radians. The latter output is provided to ensure an unambiguous record of phase fluctuations. Phase difference outputs are denoted as $\phi_{i,i+1}$ where again i denotes the antenna referenced.

3. For each interferometer pair there is a differential phase measurement provided which consists of the difference between the individual interferometer phase difference measurements. This differential phase output is the measure of the difference in the plane-wave angle-of-arrival at each interferometer in the pair. In the event that the received signal is a plane wave over the total antenna separation, this output remains constant. Hence, this output serves as a real time indicator of the existence of small scale ionization structure.

Since the basic operating principle of the lobe-sweep interferometer is similar to that of a phase-sweep interferometer system described in published literature,* only those interferometer features peculiar to the present equipment will be described here.

B. FUNCTIONAL DETAILS

The equipment essentials are summarized in the simplified block diagram of figure 1. More complete details are given in the block diagrams of figure 2 through figure 7. The interferometer antennas are mounted on remotely controlled elevation-azimuth rotators approximately forty feet above the ground, on poles which are equally spaced along a two hundred meter baseline. Preamplifiers are also mounted on the poles in proximity to each antenna to optimize system noise figures. Two calibration monopole antennas, one for each frequency, are mounted on a fourth pole removed from the interferometer antenna array. All other equipment for signal processing, recording and calibration are housed in a trailer central to the receiving antennas.

As indicated in figure 1, the input signal is amplified by the low noise preamplifiers, converted to 30 MHz, and then further amplified prior to detection. Narrow band, multi-section crystal filters with

*Lansinger, J.M. and Gagnon, R.J., "Phase-Compensated Phase-Sweep Interferometer System", IEEE Transactions on Antennas and Propagation, Vol. AP-16, Number 1, January 1968, pp. 141-143.

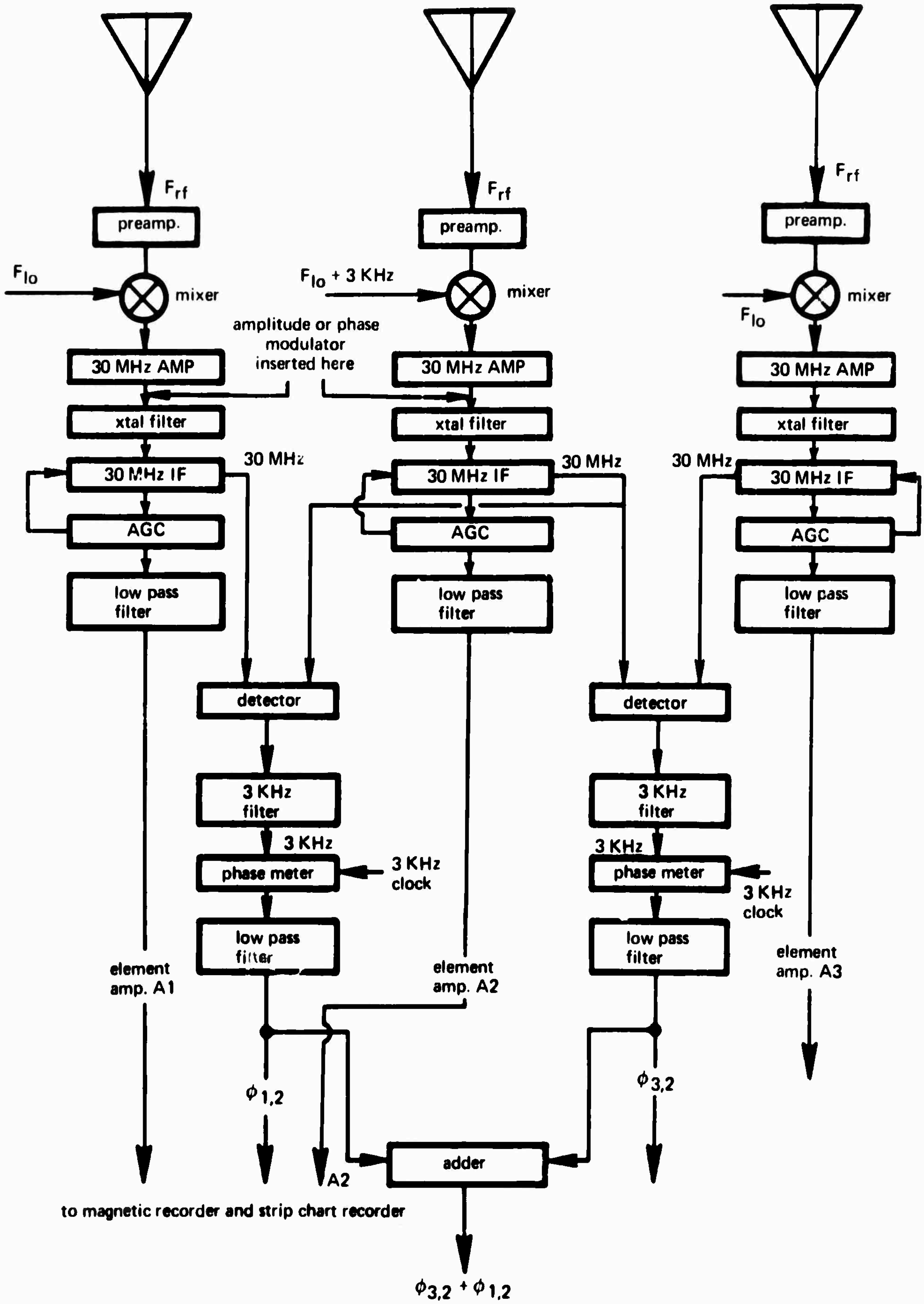
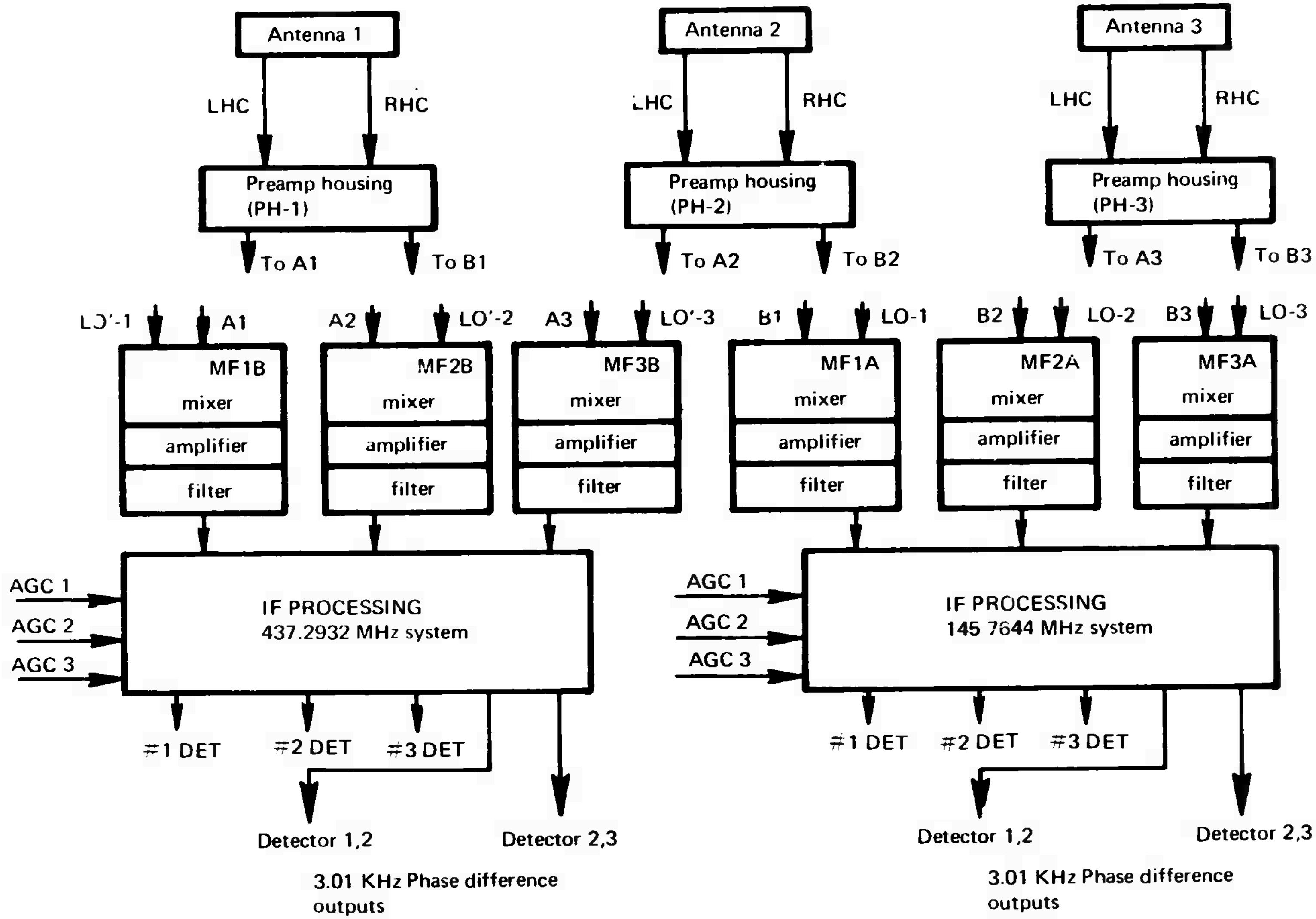


Figure 1: Simplified Block Diagram of Interferometer System



RHC = right hand polarization
LHC = left hand polarization
LO-1, LO-3 = 115.7644 MHz local oscillator signal

LO-2 = 115.7674 MHz local oscillator signal
LO'-1, LO'-3 = 407.2932 MHz local oscillator signal
LO'-2 = 407.2962 MHz

Figure 2: Block Diagram of the RF Subsystem

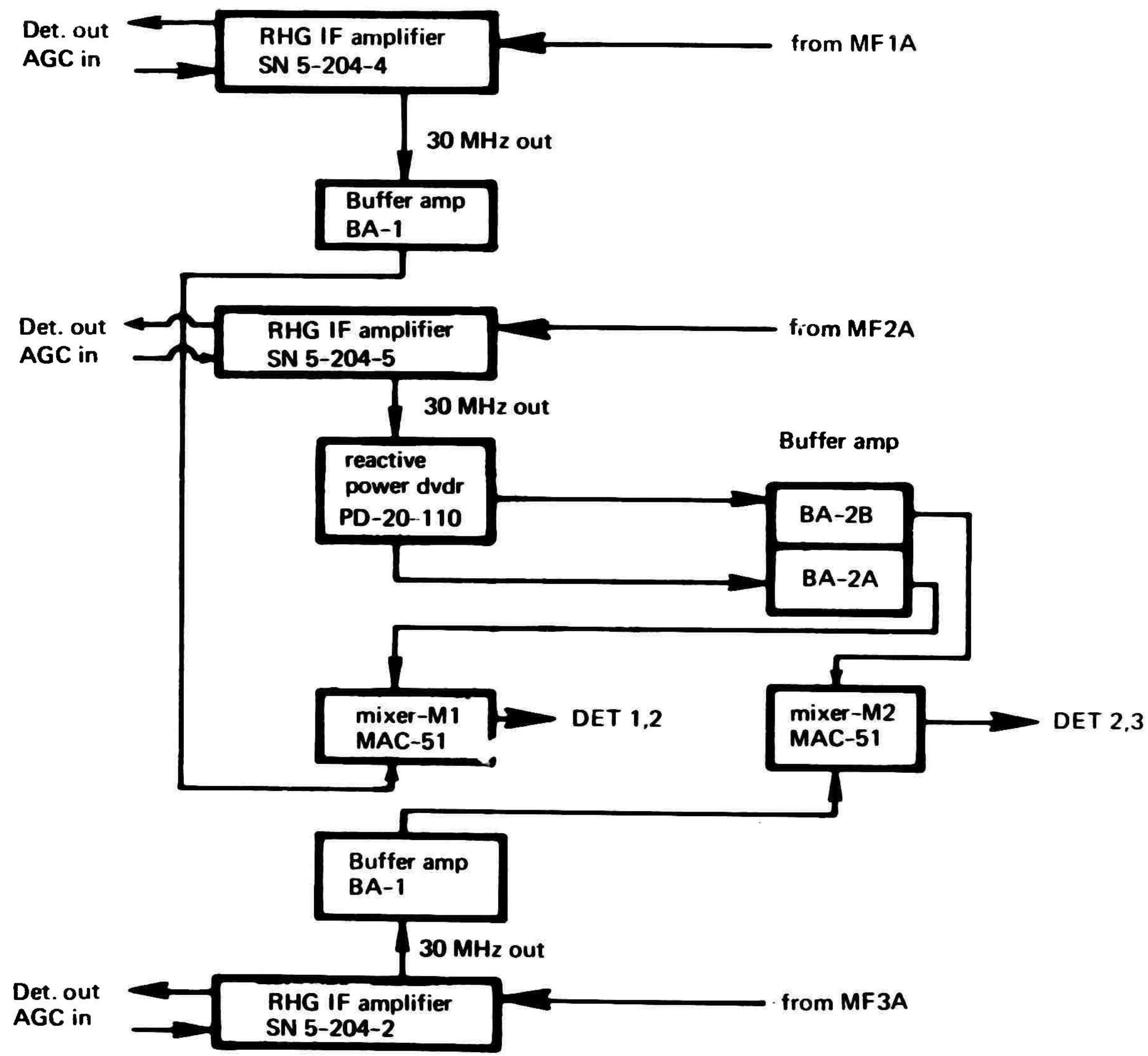


Figure 3: IF Processing for the 145.7644 MHz System

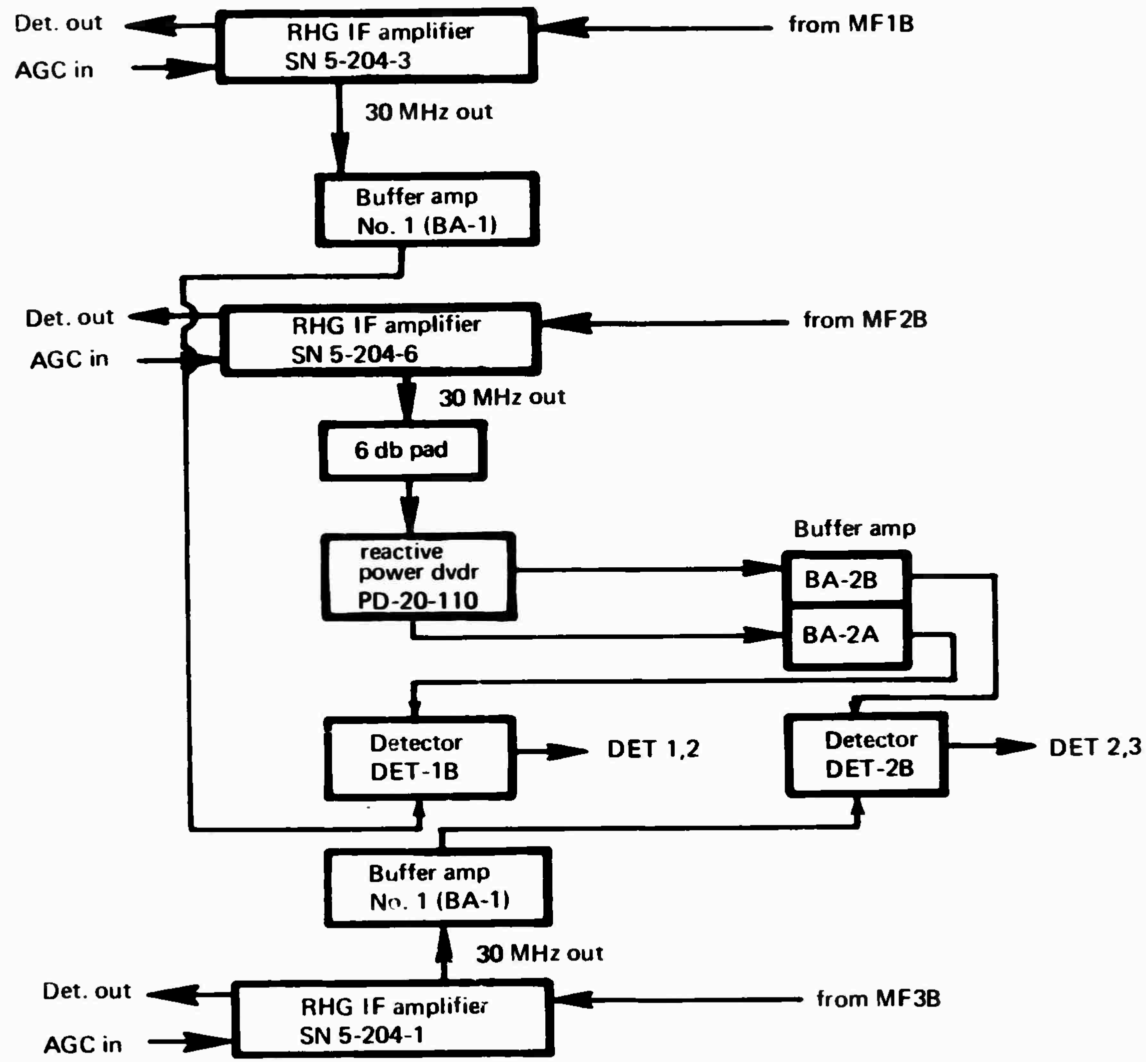


Figure 4: IF Processing for the 437.2932 MHz System

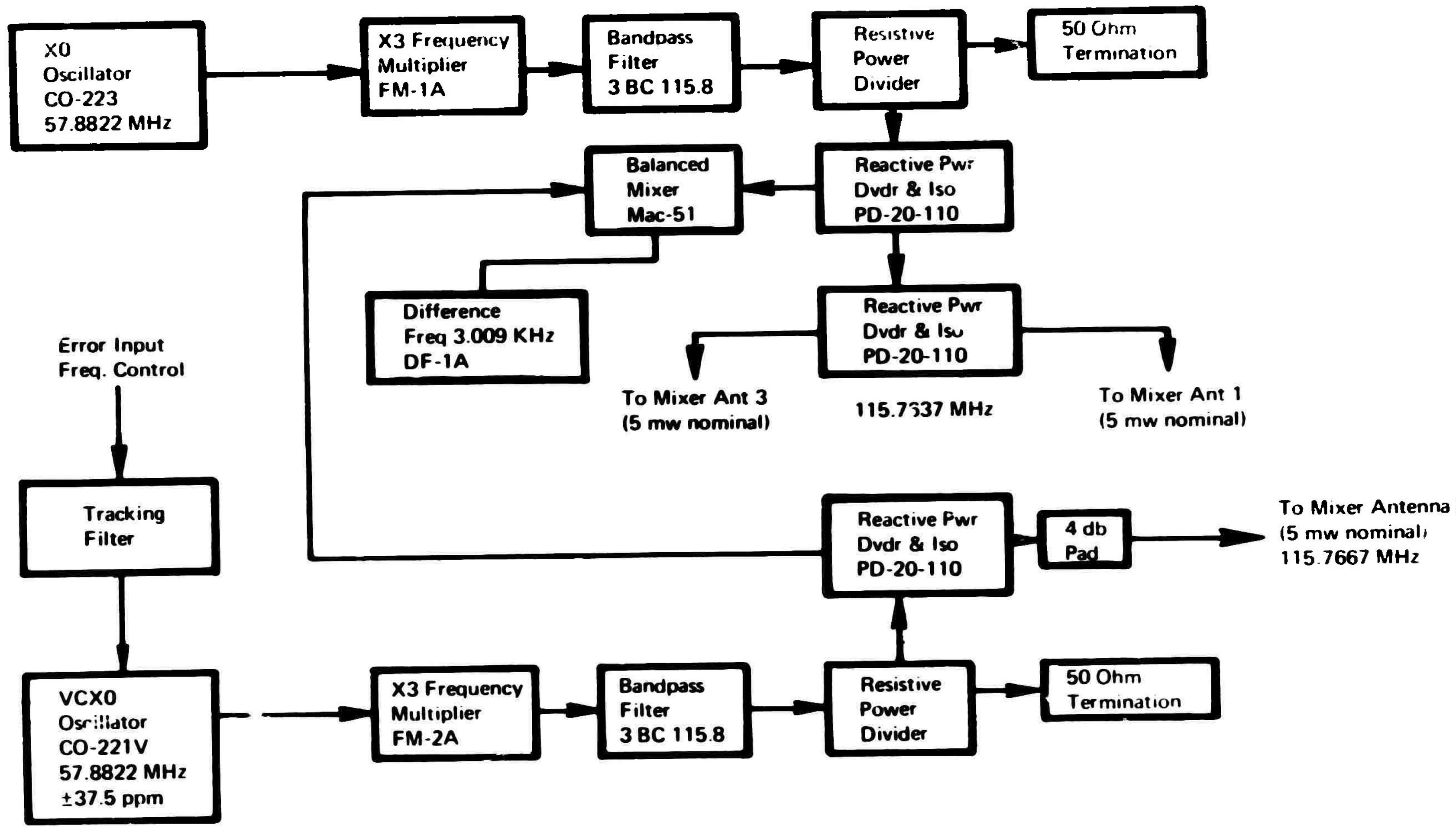


Figure 5: Block Diagram of 145.7644 MHz Local Oscillator Subsystem

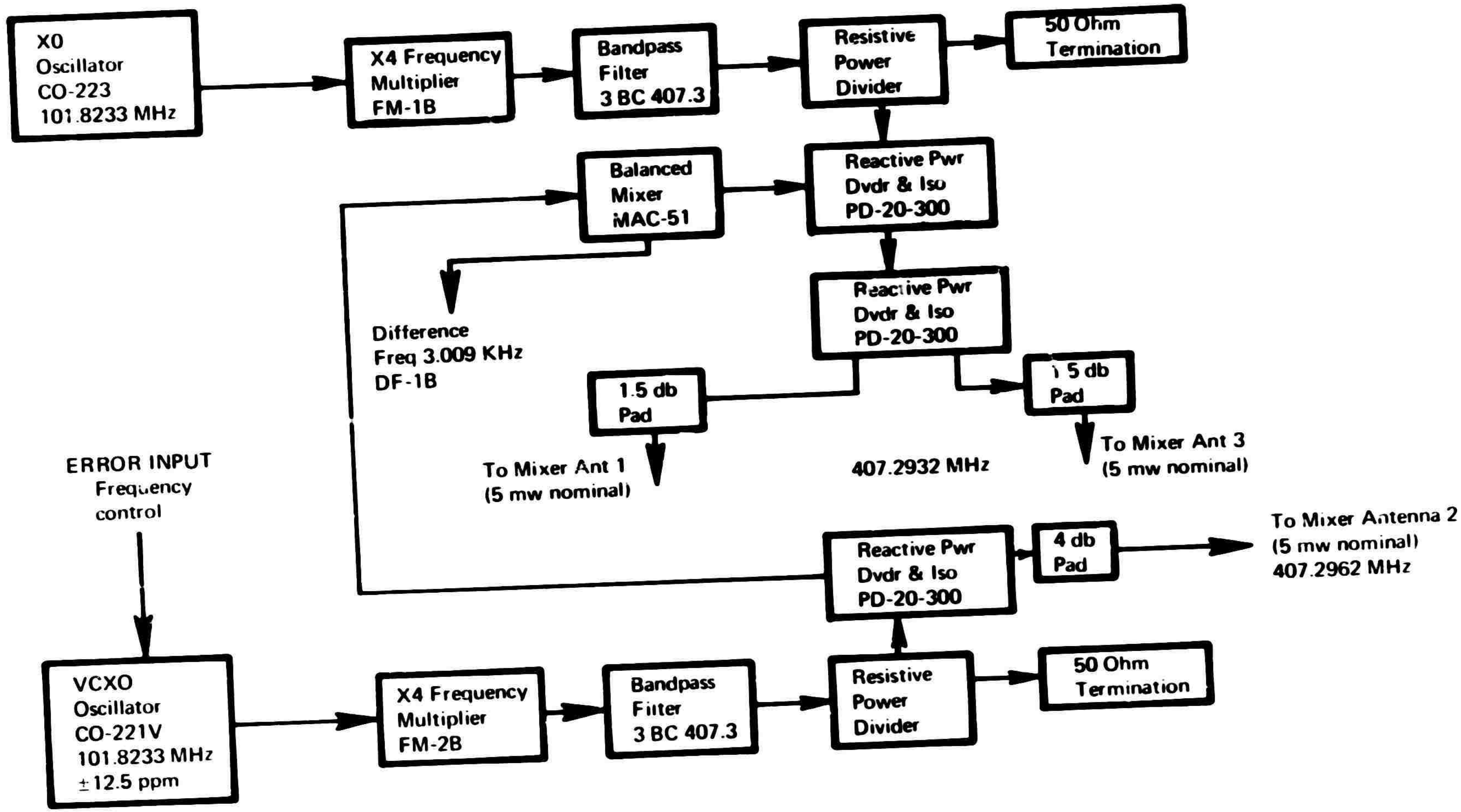


Figure 6: Block Diagram of 437.2932 MHz Local Oscillator Subsystem

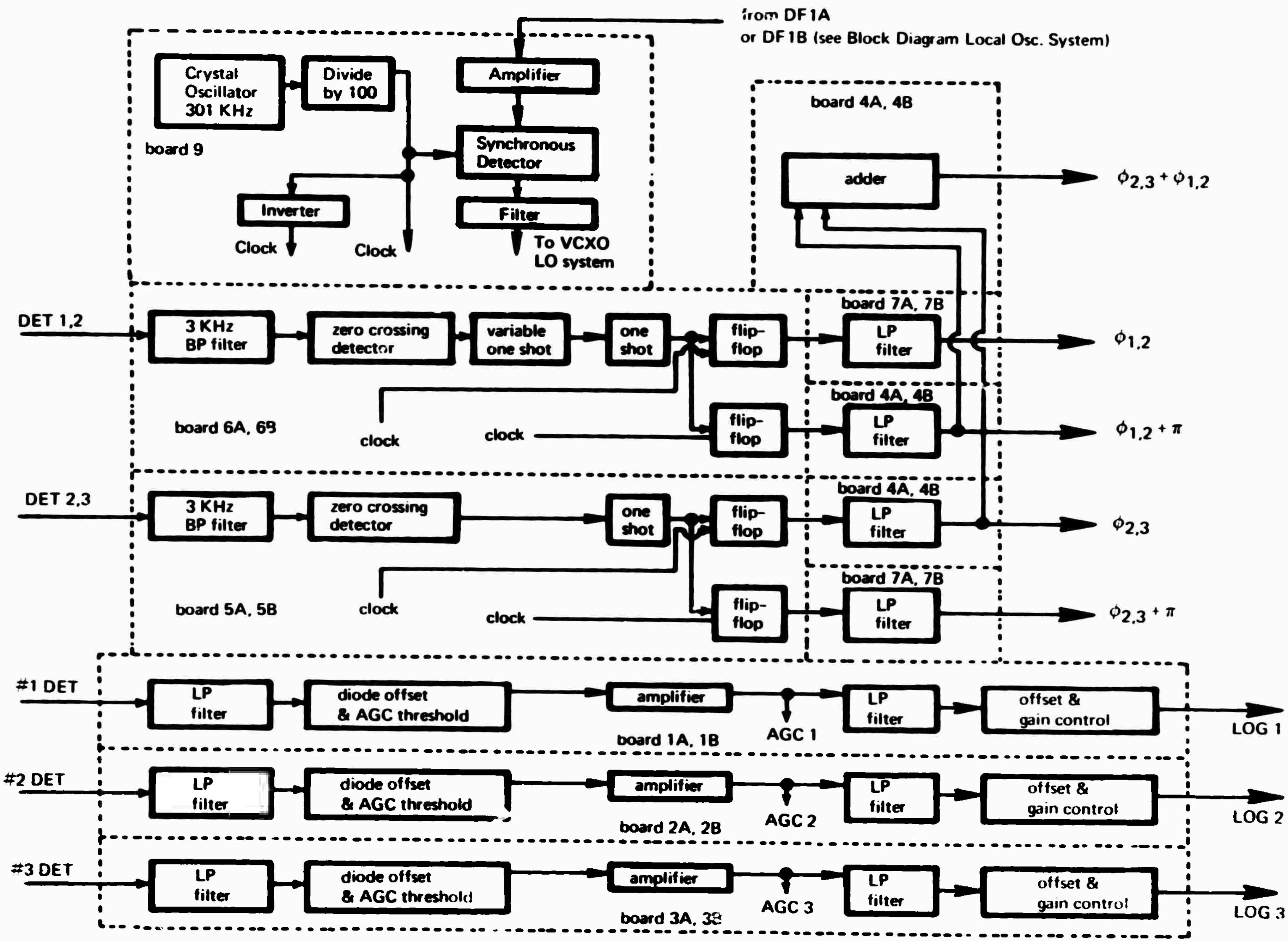


Figure 7: Block Diagram fo: Video Processing Subsystem

9 KHz passbands are used in the 30 MHz amplifier chain to limit the predetection noise bandwidth, while still providing adequate bandwidth to account for system instabilities and Doppler shifts. The quasi-logarithmic amplitude outputs are taken for recording from the AGC circuit controlling the gain of the 30 MHz amplifiers. The amplitude output response is determined by the slope of the AGC voltage versus IF amplifier gain curves.

A frequency offset of 3 KHz between local oscillator signals driving the mixers is employed for the phase measurements, and is accomplished by the phase lock system, parts of which are shown in figures 5, 6 and 7. When the signals from the antennas of an interferometer pair are mixed, the phase of the resulting 3 KHz difference frequency relative to the 3 KHz system clock is a measure of the path difference between these antennas.

The phase meter (figure 7) consists of conventional flip-flops which are set by the positive zero crossing of the reference clock and reset by the positive crossing of the signals. The output of the phase meter, i.e., the output of the adder, is therefore a measure of the phase difference between the reference and the signal, or of the differential phase as defined earlier.

C. SPECIAL DESIGN CONSIDERATIONS

1. RF SYSTEM

To meet the performance specifications established for this equipment in regard to limitations imposed by system noise at marginal signal levels, it was necessary to (1) use preamplifiers with a maximum noise figure of 3.5 db, and (2) to limit the 30 MHz passband to approximately 9 KHz. Additionally, special low loss coaxial cable exhibiting 1.8 db attenuation per one hundred feet at 438 MHz has been used as the signal link between the pole-mounted preamplifiers and the trailer-housed equipment. It was also necessary for proper system operation to minimize cross-coupling between signal channels. The buffer amplifiers, balanced mixers and isolators shown in figures 3 through 6 have been selected to provide the necessary isolating properties to insure compliance with specifications.

Fixed and voltage-controlled crystal oscillators (VCXO) stable to within 2×10^{-8} per day and $\pm1\times10^{-7}$ parts over a temperature range of 0°C to 50°C have been used to generate the local oscillator signals. Special care had to be taken to ensure that the differential frequency drift due to crystal aging and ambient temperature changes was compatible with the operating range of the VCXO which was restricted to minimize problems associated with jitter and phase instability caused by noise on the error control to the VCXO.

2. VIDEO PROCESSING

Special attention has been given to two areas in the video portion of the equipment. First, variations in the forward voltage drop across the AGC diode in the IF amplifiers resulted in a varying AGC delay threshhold. This problem was eliminated by employing matched diode pairs for cancelling the offset variation caused by temperature changes.

The second area was pre-recording filtering where, to obtain a flat passband wide enough to accommodate the data fluctuation rates while minimizing the noise content, four-pole Butterworth low-pass filters were employed. These filters have a 24 db per octave rolloff above the 3 db point.

D. CONCLUSION

While the essentials for understanding the general functioning of the SECEDE II radio interferometers are contained in the preceding description, specific circuit details which have been omitted at this time will be included in the final report on this contract.

III. BENCH TESTS

A. EQUIPMENT CONFIGURATION

The bench test set-up used for establishing compliance with specifications can be represented by figure 1 with the exception that the antennas are replaced with the calibration circuitry shown in figure 8. The test signal generator is a crystal controlled oscillator especially constructed for the system bench tests to provide 1000 microvolt signals at each of the interferometer operating frequencies, i.e., 437.2932 MHz and 145.7644 MHz. Calibration of the test signals was accomplished by using step attenuators to adjust the crystal oscillator outputs to the 1000 microvolt reference levels established by RF signal generators. A spectrum analyser was used to effect the comparison between signal sources.

The calibration test signal generators were coupled to the interferometer preamplifiers via the variable attenuators and power divider pads as shown in figure 8. The power divider, in addition to distributing the test signals to the three preamplifiers of the system under test, provides a high degree of isolation between preamplifiers, thus minimizing the problem of cross-talk. The step attenuators were used to vary the signals to the preamplifiers over the dynamic range expected during the field measurements. At the bench test reference level of -137.0 dbw obtained with the variable attenuators and power divider, the signal supplied to the preamplifiers is one microvolt. This signal, as indicated in Table I, is approximately that which is expected during field tests for the radio beacon at maximum range (for the analysis leading to the values shown in Table I, see the Appendix A).

TABLE I: EXPECTED MINIMUM
FIELD TEST SIGNAL LEVELS

Frequency (MHz)	Range (km)	Receiver Input Power (dbw)	Receiver Input Voltage (Microvolts)
437.2932	600	-139.28	0.77
145.7644	600	-132.72	1.63

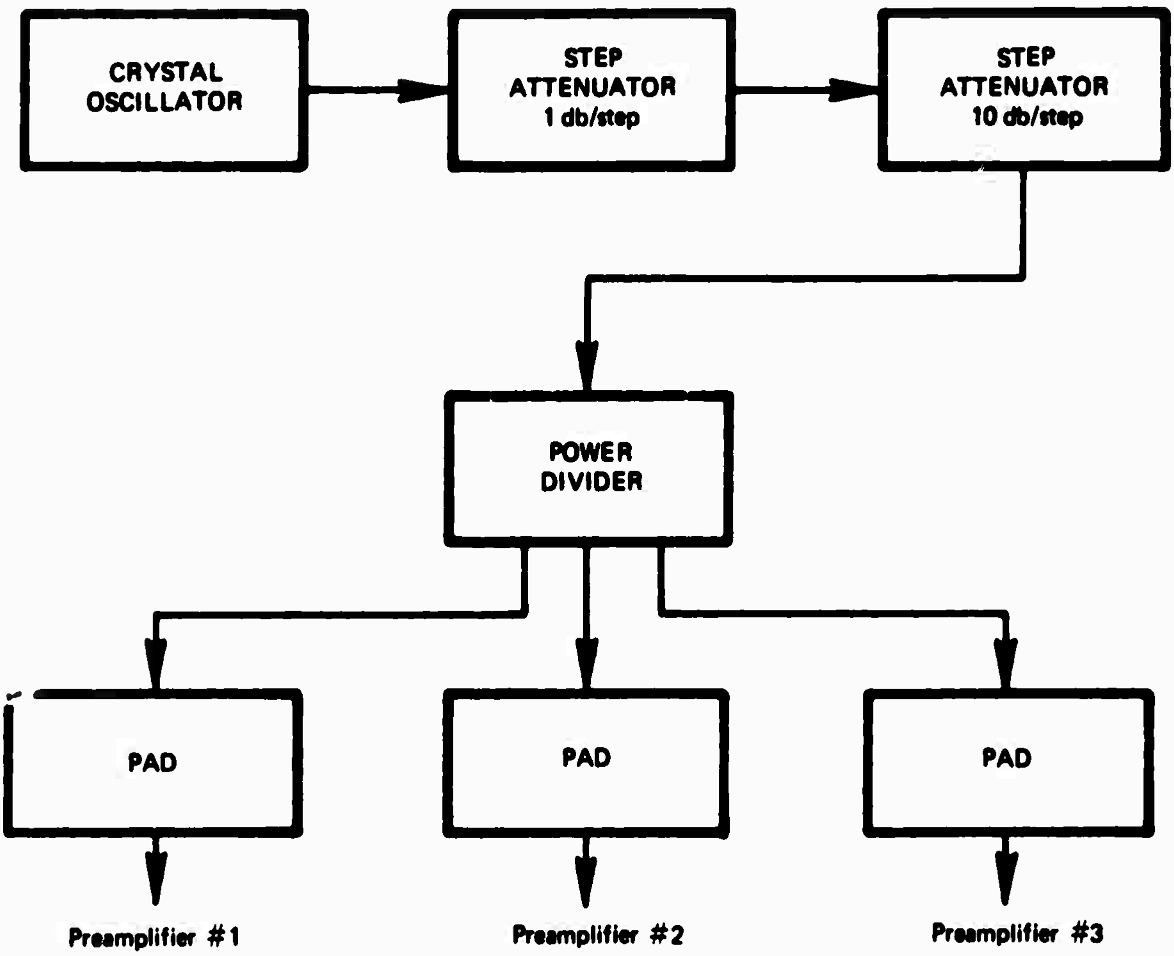


Figure 8: Signal Simulator for Bench Tests

B. CALIBRATION

Amplitude and phase modulators were inserted between the IF amplifiers and crystal filters in two channels of each interferometer (see figure 1) to perturb the test signal for the determination of the system response to signal amplitude and phase variations. The phase measurement in the normal system operation is made by comparing the signal with a 3 KHz internally generated clock reference.

1. Phase

Calibration of the phase difference measurement was accomplished by introducing a 360 degree phase shift into the system to produce full scale peak-to-peak output variation. The output gain was then adjusted until the voltage output corresponding to the 360 degree phase change varied ±1080 millivolts. The output sensitivity of the phase measurement was thus established at six millivolts per degree phase change.

2. Amplitude

Amplitude calibration was determined from the slope of the AGC voltage-gain characteristics curve of the system IF amplifiers. The performance of the AGC associated electronics was adjusted such that a 40 db input signal amplitude range produces an output voltage range of ±1.4 volts. The output sensitivity of the amplitude measurement is thus 65 millivolts per 0.5 db signal amplitude change.

C. BENCH TEST RESULTS

Descriptions of the bench test procedures used to determine the performance of the interferometer system relative to the stated specifications follow.

1. Specification: Operating frequency, minimum 3 db IF bandwidth, Doppler shift tolerance

System operation has to be accomplished over an operative bandwidth sufficient to take into account Doppler frequency shifts in the received signals attributable to rocket motions. The 3 db IF bandwidth of the system is determined by the nominally 9 KHz 3 db bandwidth of the 30 MHz crystal filters. The center frequency and bandwidth of these filters is documented in manufacturer specifications given in Appendix B. It is required that the difference frequency between the receiving frequency and local oscillator frequency be within the 3 db bandwidth of the bandpass

filters, with adequate allowance taken for Doppler shift tolerance. This was verified by comparing the filter data with bench test results of the measured local oscillator frequency. The relevant frequencies are: 145.7644 MHz and 437.2932 MHz for the receiving frequencies, and 115.7644 MHz and 407.2932 MHz for the local oscillators. Bench measurement results for this specification are given in Appendix C.

2. <u>Specification</u>: Element amplitude, deviation from mean signal voltage level

The amplitude output from each simulated interferometer element was monitored with the chart recorder and an oscilloscope as the input signals were varied about the 0 db reference level with a step attenuator. System sensitivity to an increment change of 1 db was noted and deviations due to noise and receiver instabilities at various signal levels was recorded. Measurements for this specification are summarized in Appendix C, with representative oscilloscope photographs showing receiver noise limitations presented in Appendix D.

3. <u>Specification</u>: Margin for instantaneous peak signal

Compliance with this specification was determined by increasing the input signal until the AGC voltage reached full scale. The input level at this point was recorded. Measurement results are summarized in Appendix C.

4. <u>Specification</u>: Error in recovered phase difference due to noise and system instabilities; deviation in phase with variations in input signal level

This specification was checked by monitoring the phase with an oscilloscope and chart recorder while performing the phase calibration procedures described previously. The variations in phase due to noise and receiver instabilities were recorded and measured as a function of input signal level as this level was varied over a large dynamic range. Test results are summarized in Appendix C with representative oscillograph photographs shown in Appendix E.

5. <u>Specification</u>: Amplitude and phase 3 db cutoff frequencies

The amplitude and phase 3 db cutoff frequencies are specified to be 150 Hz and 60 Hz at 145.7644 MHz and 407.2932 MHz, respectively.

Amplitude and phase characteristics were checked independently by inserting an amplitude or phase modulator into the system and observing the system response. For amplitude response determinations, a small variation in signal, of order 1-2 db, was introduced into the system and the appropriate amplitude channel was monitored with an oscilloscope while the modulation frequency was varied. Similarly, using a phase modulator and monitoring a phase difference channel, the response for a phase difference measurement was determined. Results of these tests are summarized in Appendix F.

6. Specification: Antennas and antenna mounts

Three broadband log-periodic circularly polarized antennas specifically designed to meet the outlined specifications were purchased. Each antenna was separately tested on an antenna range, and the acquired polar patterns are presented in Appendix F.

To demonstrate the applicability of a two-axis mount specially designed for the intended field use, one of these antennas was installed on a mock-up pole in the laboratory. Such factors as the resetability of orientation, method of installation, and safety from self-destruction were tested and found acceptable as applied to the anticipated SECEDE II program.

IV. RECORDING SYSTEMS

The data recording systems are compatible with the interferometer outputs discussed previously. Amplitude and phase difference data from each element of the four interferometers are recorded at 15 ips on a 14-track fm magnetic tape recorder. IRIG B time is recorded on one of the channels. A back-up Ampex 4-track fm tape recorder is also employed to record additional phase data. Both magnetic recorders operate in accordance with standard IRIG specifications. The tentative recording plan is outlined in Table II. Data from selected system outputs are also recorded on an 8-channel strip chart recorder. Time data is also placed on the strip chart recorder by using a IRIG B time code reader and keying minute and second event pens on the recorder at one minute

and one second intervals. The strip chart records provide a real-time indication of the performance of the interferometers during the field measurements, and will further serve to indicate the occurrence of significant events within any data run. Such identification will aid in the selection of data intervals for detailed analysis of the magnetic tape data, the desired interval being isolated on the tape by monitoring the tape recorded time data with the time code reader. Preliminary data analysis will be accomplished by playback of the original magnetic tape recording at 3 1/2 or 1 7/8 ips. This stretches the original time record by a factor of 4 or 8, respectively. Selected channels of information will also be recorded on the strip chart recorder during playback. It is anticipated that the fastest fluctuations in the recorded data will not exceed 150 Hz. This frequency will be converted to about 19 Hz at a playback of 1 7/8 ips, a frequency well within the recording capability of the recorder. The original magnetic tape records will be digetized for complete computer analysis of the data following completion of the SECEDE II test events. The relevant specifications of the recorders are as follows:

Magnetic tape recorder

- Signal-to-noise: 44 db
- Drift: Less than 1% in a 24-hour period
- Linearity: Within 1% p - p deviation
- Frequency Response: 0-5000 Hz at 15 ips
0-1250 Hz at 3 3/4 ips
0-625 Hz at 1 7/8 ips
- Recording Time at 15 ips: 48 minutes

Strip Chart Recorder

- Linearity: 1%
- Rise Time: 5 milliseconds
- Overshoot: 1%

TABLE II

PROPOSED MAGNETIC DATA RECORDING SCHEME

Track No.	DATA (145.7644 MHz)	DATA (437.2932 MHz)
	Recorder No. 1	
1	Log 1	
2	Log 2	
3	Log 3	
4	$\phi_{1,2}$	
5	$\phi_{2,3}$	
6	$\phi_{1,2} + \pi$	
7	$\phi_{2,3} + \pi$	
8		Log 1
9		Log 2
10		Log 3
11		$\phi_{1,2}$
12		$\phi_{2,3}$
13		$\phi_{1,2} + \pi$
14 IRIG B Time		
	Recorder No. 2	
1		$\phi_{2,3} + \pi$
2	differential phase	
3		differential phase
4 IRIG B Time		

APPENDIX A

DETERMINATION OF MINIMUM SIGNAL INPUT LEVELS

The power at the interferometer receivers can be calculated from

$$P_{rx} = (g_{rx} + g_t + P_t - \alpha) \text{ dbw} \tag{1}$$

where P_t and P_{rx} denote the transmitted and received powers, g_t and g_{rx} the transmitter and receiver gains, and α is the free space attenuation. This latter quantity, in turn, is given by

$$\alpha = 37 + 20\log(f) + 20\log(d), \tag{2}$$

where f is frequency in MHz and d is range in miles. Using equation (2), the free space attenuations at 437.2932 MHz and 145.7644 MHz for the maximum beacon-to-receiver range of 373.8 miles (600 km) are calculated as:

$$\alpha_{437} = 141.28 \text{ db}$$

$$\alpha_{145} = 131.72 \text{ db.}$$

Using the above values of α, and with

$$g_t = -6 \text{ db; } g_{rx} = 5 \text{ db; } P_{t_{437}} = 3 \text{ dbw; } P_{t_{145}} = 0 \text{ dbw,}$$

the minimum received powers at the two interferometer frequencies are calculated from equation (1) as

$$P_{rx_{437}} = -139.28 \text{ dbw}$$

$$P_{rx_{145}} = -132\ 72 \text{ dbw.}$$

The minimum rms system input voltages associated with the above minimum power levels are thus

$$V_{rms_{437}} = 0.77 \text{ microvolts}$$

$$V_{rms_{145}} = 1.63 \text{ microvolts.}$$

APPENDIX B

MANUFACTURERS SPECIFICATIONS - 30MHz CRYSTAL BANDPASS FILTERS

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CRYSTAL FILTER DATA SHEET
CUSTOMER REQUIREMENTS

CUSTOMER NETL　　DATE 9-30-70

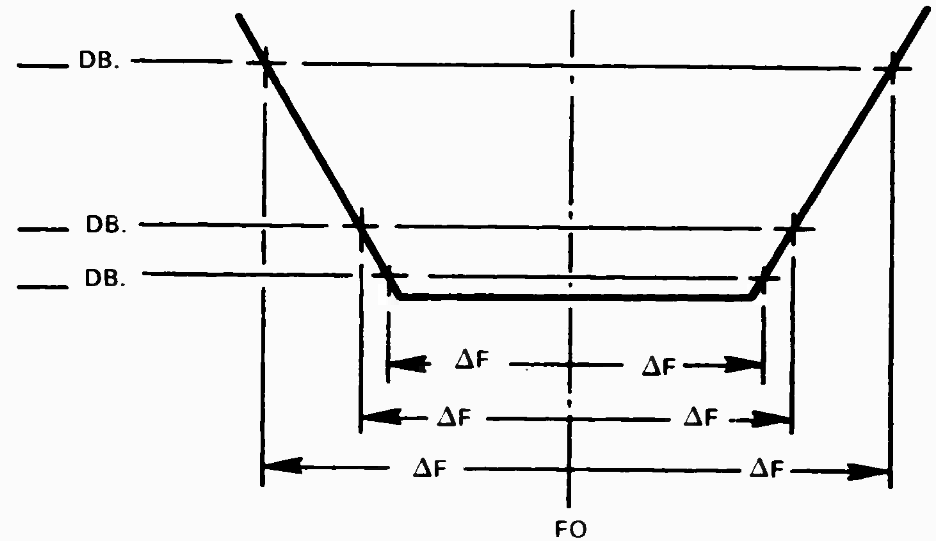
P.O. NO. ______　　MODEL NO. 954

ELECTRICAL SPECIFICATIONS

C.F. 30 mc　RIPPLE ______　INSERTION LOSS ______

__DB. BW ______　__DB. BW ______　__DB. BW ______

OTHER =



FILTER S. N.	FILTER TYPE	ΔF L-3	ΔF U-3	BW	ΔF L-60	ΔF U-60	BW	C.F.	BW	RIPPLE db	I.L. db	REMARKS
#1		4280	4620	8900	22900	22650		30000170		.5	5.3	
#2		4320	4700	9020	14180	17540		30000190		0	3.8	
#3		4280	4350	8630	21680	23920		30000035		.1	5.3	
#4		4350	4480	8830	21500	24000		30000065		.6	4.0	TEST DATE 10-5-70
#5		4280	4310	8590	16000	21662		30000015		5	5.0	TEST DATE 10-5-70
#6		4080	4890	8970	18900	25300		30000450		3	3.6	TEST DATE 10-27-70

APPENDIX C

SUPPORTING DOCUMENTATION FOR THE BENCH TEST MEASUREMENTS OF THE VARIATION OF ELEMENT AMPLITUDE AND PHASE DIFFERENCE DUE TO NOISE AND SYSTEM INSTABILITIES

	Frequencies in MHz		Measured Value xtal osc	Measured Value var xtal osc
Local Oscillator Frequency	system =1	115.7644	115.76430	115.7637
Test Generator Frequency	system =1	145.7644	145.7650	

Attenuator pad setting for 1 microvolt or -137 dbw input into preamplifier: 36 db (this is the 0 db ref. level) (max. range if 40 db)

	Input Level (db)	log-1	log-2	log-3
element amplitude output for indicated input level	-10.	-1.63	-1.45	-1.36
Output listed in volts	0.	-1.18	-1.06	-1.00
	+10.	- .62	- .54	- .51
	+20.	+ .14	+ .16	+ .18
	+30.	+1.24	+1.16	+1.20
IF detected output (volts)	(0) db input level	IF =1	IF =2	IF =2
		+ .443	+ .275	+ .461
AGC voltage	(0) db input leve	-1.40	-1.06	-1.46

	Input Level (db)	Channel 1 (mv)	Channel 2 (mv)	Channel 3 (mv)
Peak-to-peak variation in element amplitude due to noise and receiver instabilities at level indicated	-10.	40.	20.	20.
	0.	20.	10.	10.
	+10.	5.	3.	3.

at 0 db reference level

1 db change = 35. mv channel 1
1 db change = 35. mv channel 2
1 db change = 35. mv channel 3

Element Amplitude and Phase Measurements—145.7644 MHz System

Element Amplitude and Phase Measurements—145.7644 MHz System—continued

	Channel 1 (db)	Channel 2 (db)	Channel 3 (db)
Margin for instantaneous peak signal over mean level for recorder full scale	35	35	35

Peak-to-peak variation due to noise and receiver instabilities at power levels shown

9.15^{o} p-p (2 normal dist.) corresponds to .04 radians rms

	Phase 1,2		Phase 2,3		Phase 1,2 (180^{o})		Phase 2,3 (180^{o})	
db level	mv	degrees	mv	degrees	mv	degrees	mv	degrees
-10.0	80.	13.3	80.	13.3	80.	13.3	80.	13.3
0.0	20.	3.3	20.	3.3	20.	3.3	20.	3.3
+10.0	5.	.8	5.	.8	5.	.8	5.	.8
+20.0	3.	.5	2.	.3	2.	.3	3.	.5

6 mv = 1^{o}

mean change in recovered phase deviation due to a change in input level at the indicated level listed

	Phase 1,2		Phase 2,3	
db level	mv	degrees	mv	degrees
0.0	0.	0.	0.	0.
+10.0	-22.	-3.67	-15.	-2.5
+20.0	-30.	-5.0	-15.	-2.5
+30.0	-32.	-5.3	-10.	-1.6

	Phase 1,2 (Hz)	Phase 2,3 (Hz)	Phase 1,2 (180^{o}) (Hz)	Phase 2,3 (180^{o}) (Hz)
-3 db response frequency for a phase variation of 13.3^{o}	160.	160.	170.	145.

	Channel 1 (Hz)	Channel 2 (Hz)	Channel 3 (Hz)
-3 db response frequency for an amplitude change of 1.5 db	155.	160.	165.

Local Oscillator Frequency	system #2	407.2932	407.2931	407.2961
Test Generator Frequency	system #2	437.2932	437 2953	

Attenuator pad setting for 1 microvolt or -137 dbw input into preamplifier: 54 db (this is the 0 db ref. level) (max. range is 56 db)

	Input Level (db)	log-1	log-2	log-3
Element amplitude output for indicated input level	-10.	-1.37	-1.54	-1.56
Output listed in volts	0.	- .76	- .87	- .91
	+10.	- .37	- .47	- .52
	+20.	+ .44	+ .39	+ .37
	+30.	+1.57	+1.60	+1.67
IF detected output (volts)	(0) db input level	IF #1	IF #2	IF #2
		+ .480	+ .485	+ .489
AGC voltage	(0) db input level	-1.59	-2.16	-1.45

	Input Level (db)	Channel 1 (mv)	Channel 2 (mv)	Channel 3 (mv)
Peak-to-peak variation in element amplitude due to noise and receiver instabilities at level indicated	-10.	30.	25.	30.
	0.	10.	10.	10.
	+10.	5.	5.	5.

at 0 db reference level

1 db change = 45 mv channel 1
1 db change = 45 mv channel 2
1 db change = 50 mv channel 3

Element Amplitude and Phase Measurements—437.2932 MHz System

Element Amplitude and Phase Measurements—437.2932 MHz System—Continued

	Channel 1 (db)	Channel 2 (db)	Channel 3 (db)
Margin for instantaneous peak signal over mean level for recorder full scale (mean level corresponds to 0 db reference)	30.	30.	30.

Peak-to-peak variation due to noise and receiver instabilities at power levels shown

9.15° p-p (2 normal dist.) corresponds to .04 radians rms

db level	Phase 1,2 mv	Phase 1,2 degrees	Phase 2,3 mv	Phase 2,3 degrees	Phase 1,2 (180°) mv	Phase 1,2 (180°) degrees	Phase 2,3 (180°) mv	Phase 2,3 (180°) degrees
-10.0	90.	15.	75.	12.	90.	15.	75.	12.
0.0	25.	4.2	20.	3.3	25.	4.2	20.	3.3
+10.0	10.	1.6	7.	1.2	10.	1.6	7.	1.2
+20.0	5.	.8	3.	.5	5.	.8	3.	.5

6 mv = 1°

Mean change in recovered phase deviation due to a change in input level at the indicated level listed

db level	Phase 1,2 mv	Phase 1,2 degrees	Phase 2,3 mv	Phase 2,3 degrees
0.0	0.	0.	0.	0.
+10.0	-20.	-3.3	+17.	+2.8
+20.0	-20.	-3.3	+17.	+2.8
+30.0	-20.	-3.3	+ 5.	+ .83

	Phase 1,2 (Hz)	Phase 2,3 (Hz)	Phase 1,2 (180°) (Hz)	Phase 2,3 (180°) (Hz)
-3 db response frequency for a phase variation of 13.3°	76	81	86	83

	Channel 1 (Hz)	Channel 2 (Hz)	Channel 3 (Hz)
-3 db response frequency for an amplitude change of .75 db	83	80	83

APPENDIX D

PHOTOGRAPHIC DOCUMENTATION FOR THE BENCH TEST MEASUREMENTS OF THE VARIATION OF ELEMENT AMPLITUDE DUE TO NOISE AND INSTABILITIES

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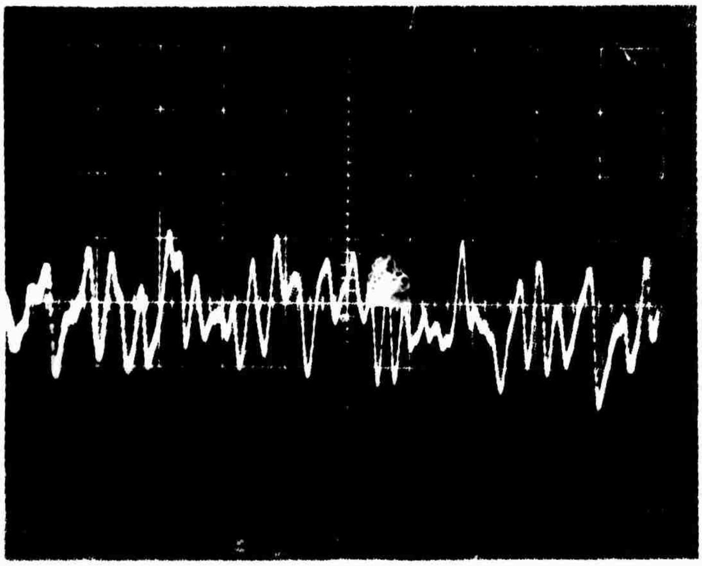
Measurement of variation in element amplitude due to noise and receiver instabilities—channel 1

System operating frequency: 145.7644 MHz

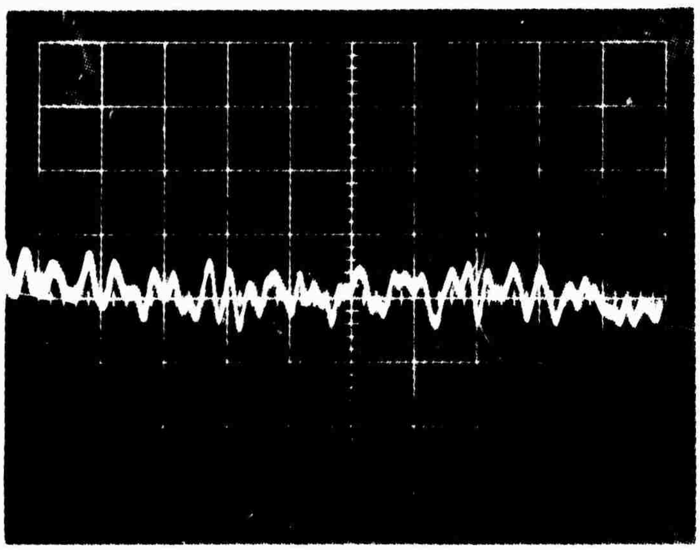
Reference level of 0 db corresponds to -137 dbw or 1 microvolt (50 ohm input impedance). At maximum range, minimum input level corresponds to -132.7 dbw or 1.6 microvolts.



Input level: -10.0 db

Vertical scale: 1 db = 2 1/2 cm

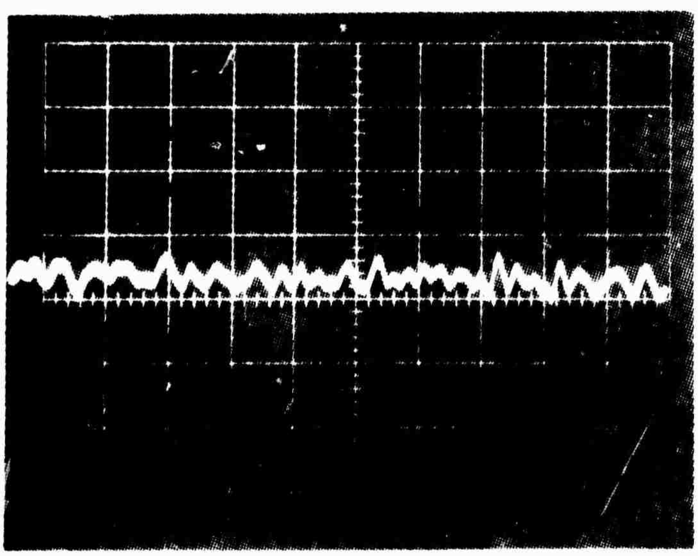
Time scale: 20 ms/cm



Input level: 0.0 db

Vertical scale: 1 db = 5 cm

Time scale: 20 ms/cm



Input level: +10 db

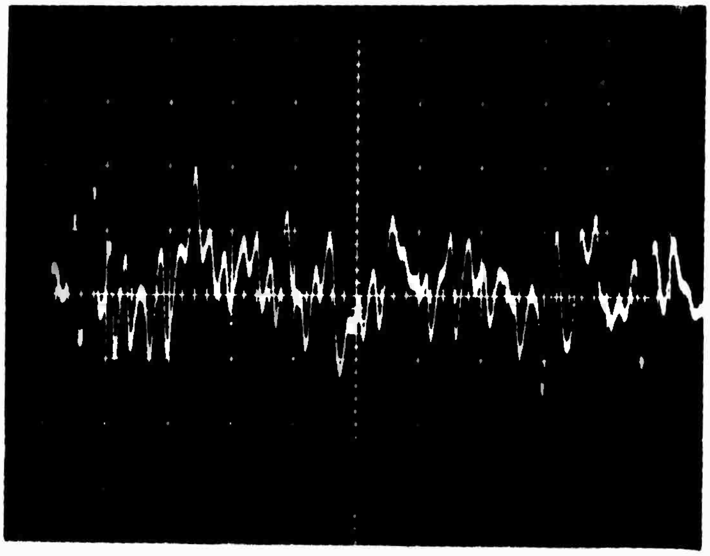
Vertical scale: 1 db = 7 1/2 cm

Time scale: 20 ms/cm

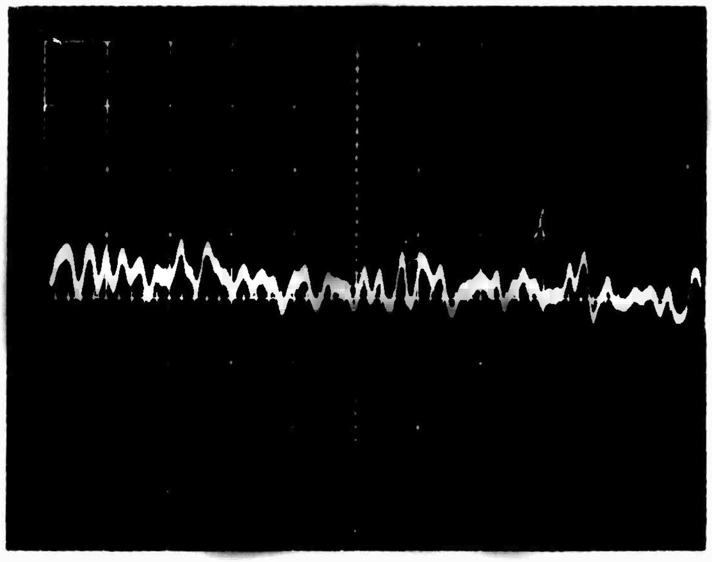
Measurement of variation in element amplitude due to noise and receiver instabilities—channel 1

System operating frequency: 437.2932 MHz

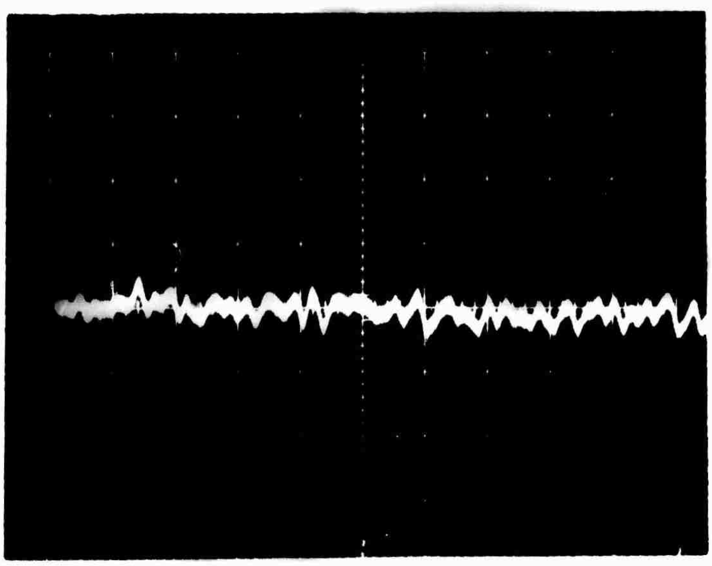
Reference level 0 db corresponds to -137 dbw input or 1 microvolt (50 ohm input impedance). At maximum range, minimum input level corresponds to -139.3 db or 0.77 microvolts.



Input level: -10 db
Vertical scale: 1 db = 4 cm
Time scale: 50 ms/cm



Input level: 0.0 db
Vertical scale: 1 db = 4 1/2 cm
Time scale: 50 ms/cm



Input level: +10 db
Vertical scale: 0.125 db/cm
Time scale: 50 ms/cm

APPENDIX E

PHOTOGRAPHIC DOCUMENTATION FOR THE BENCH TEST MEASUREMENTS OF THE VARIATION OF PHASE DIFFERENCE DUE TO NOISE AND INSTABILITIES

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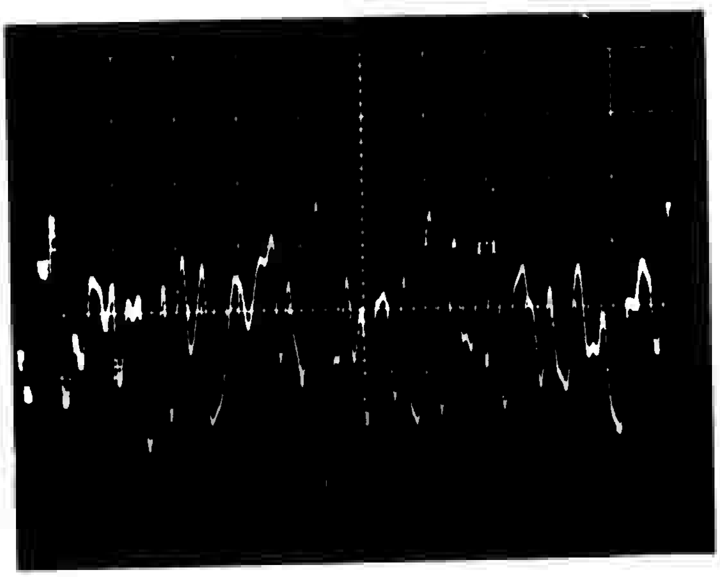
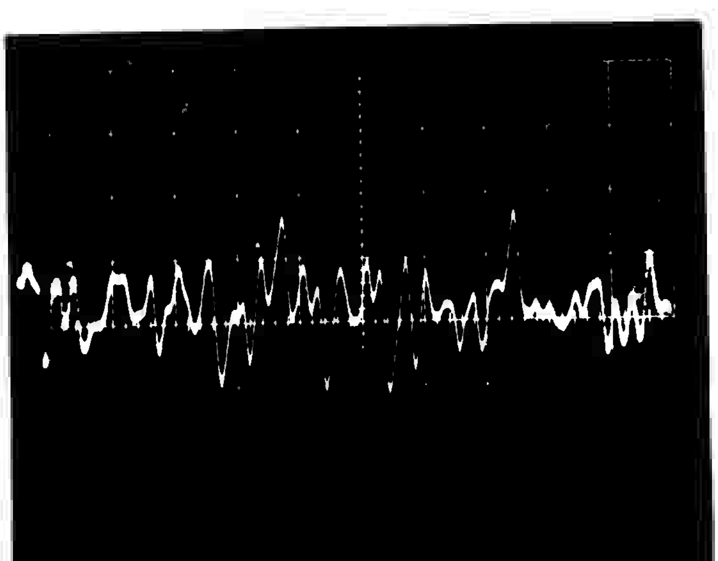
Measurement of variation in phase difference due to noise and receiver instabilities—phase $\phi_{1,2}$ channel

System operating frequency: 145.7644 MHz

Reference level of 0 db corresponds to -137 dbw or 1 microvolt (50 ohm input impedance). At maximum range, minimum input level corresponds to -132.7 dbw or 1.6 microvolts.



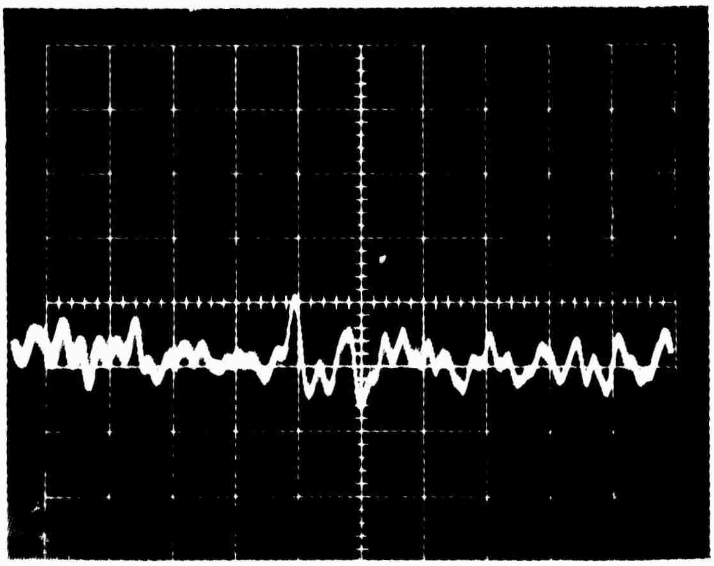
Input level: -10 db
Vertical scale: 1.66 degrees/cm
Time scale: 20 ms/cm



Input level: 0.0 db
Vertical scale: 1.66 degrees/cm
Time scale: 20 ms/cm

Measurement of variation in phase difference due to noise and receiver instabilities—continued

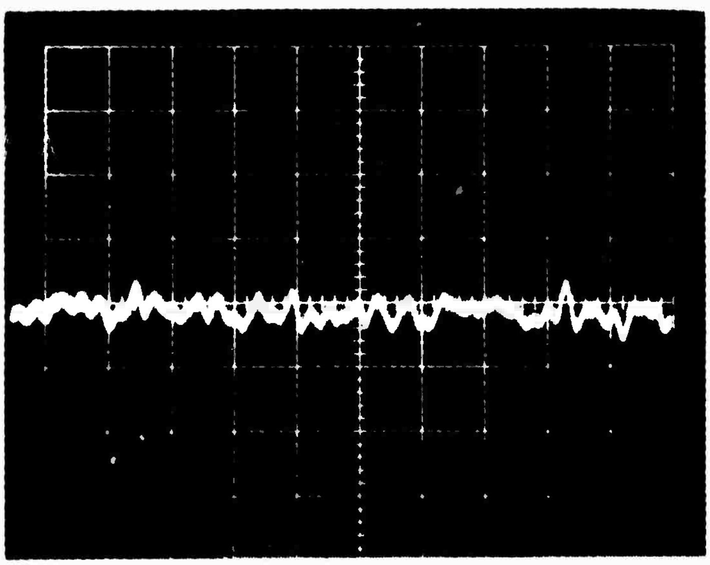
System operating frequency: 145.7644 MHz



Input level: +4 db

Vertical scale: 1.66 degrees/cm

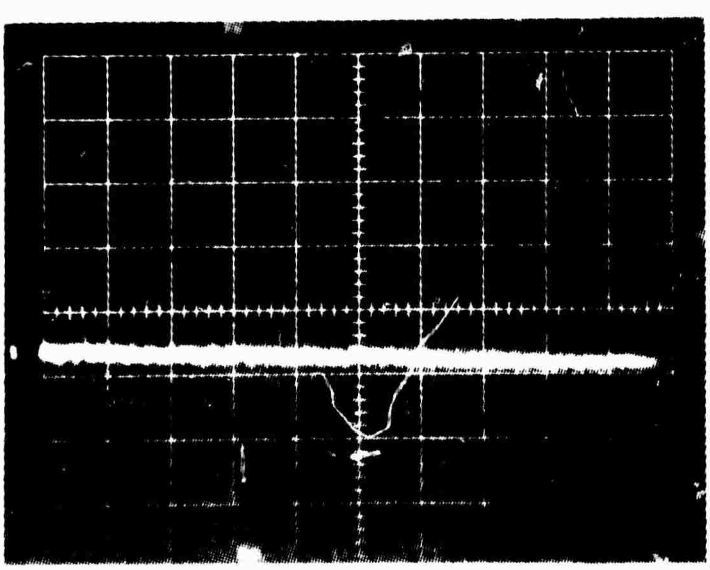
Time scale: 20 ms/cm



Input level: +10 db

Vertical scale: 1.66 degrees/cm

Time scale: 20 ms/cm



Input level: +14 db

Vertical scale: 1.66 degrees/cm

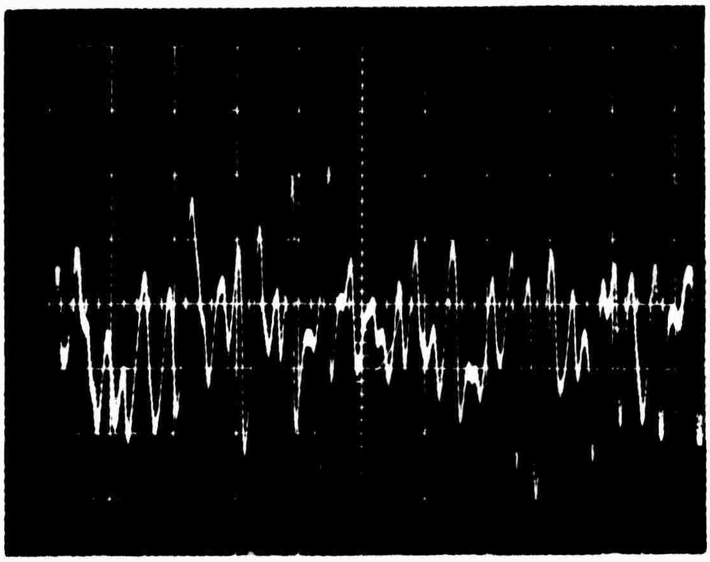
Time scale: 2 seconds/cm

Note that the slope is not due to drift, but due to camera misalignment.

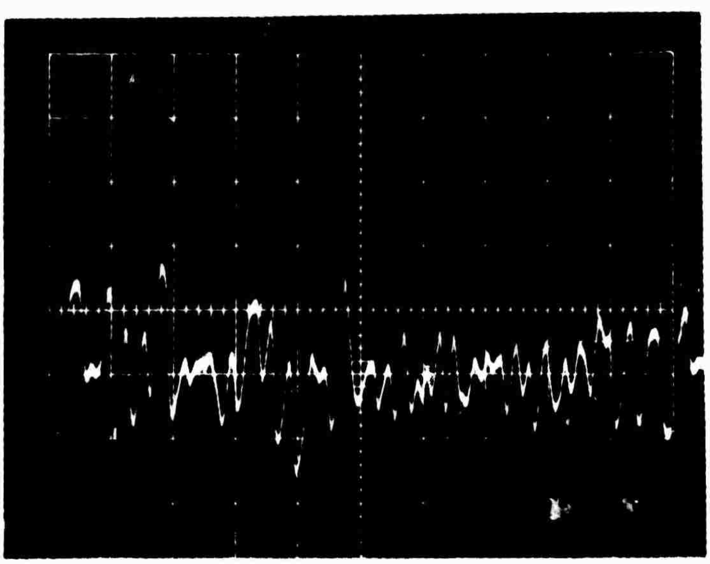
Measurement of variation in phase difference due to noise and receiver instabilities

System operating frequency: 437.2932 MHz

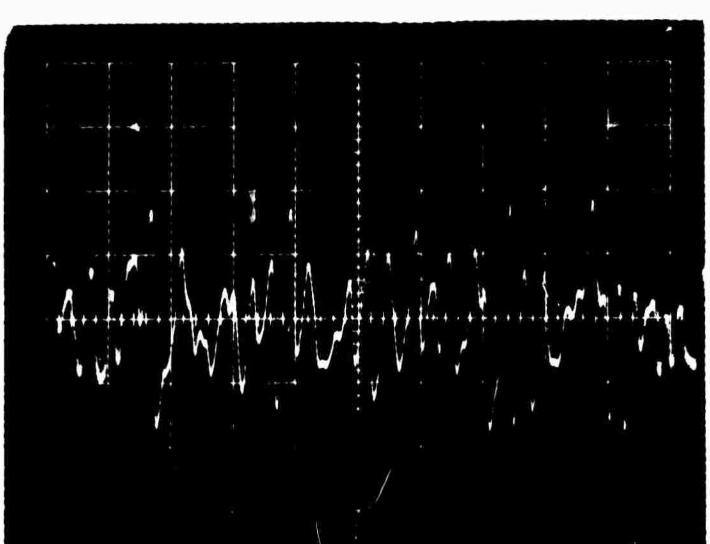
Reference level 0 db corresponds to -137 dbw input or 1 microvolt (50 ohm input impedance). At maximum range, minimum input level corresponds to -139.3 db or 0.77 microvolts.



Phase $\phi_{1,2}$ channel
Input level: -3 db
Vertical scale: 1.67 degrees/cm
Time scale: 50 ms/cm



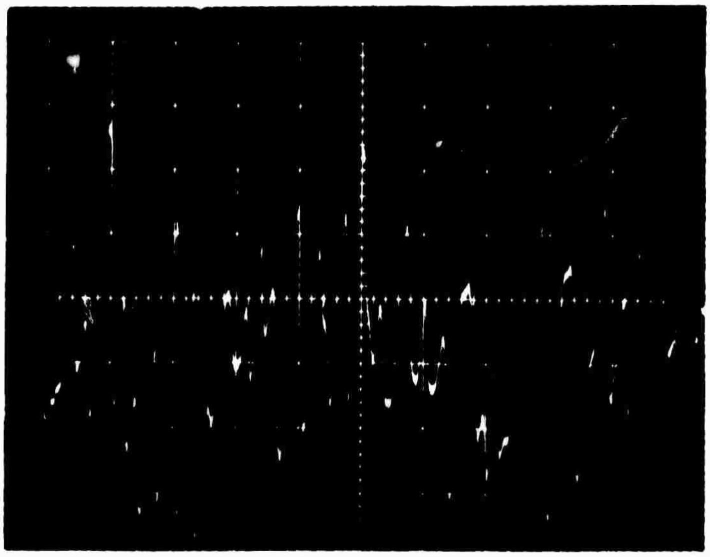
Phase $\phi_{1,2}$ channel
Input level: 0.0 db
Vertical scale: 1.67 degrees/cm
Time scale: 50 ms/cm



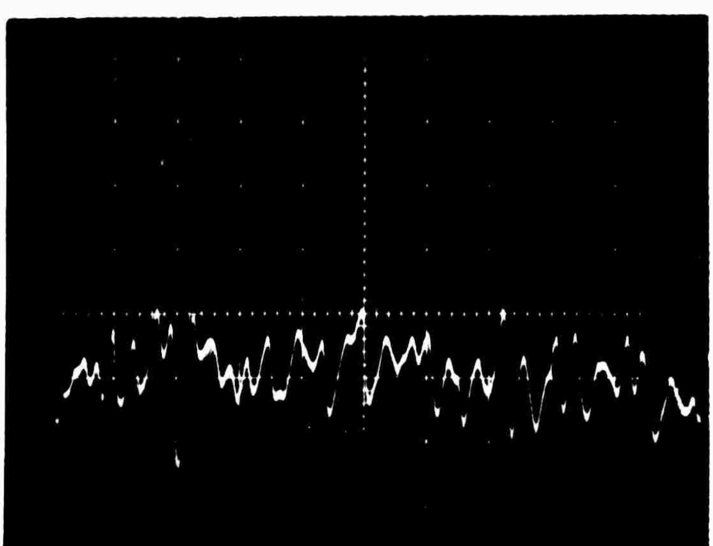
Phase $\phi_{2,3}$ channel
Input level: -10 db
Vertical scale: 3.34 degrees/cm
Time scale: 50 ms/cm

Measurement of variation in phase difference due to noise and receiver instabilities—continued

System operating frequency: 437.2932 MHz



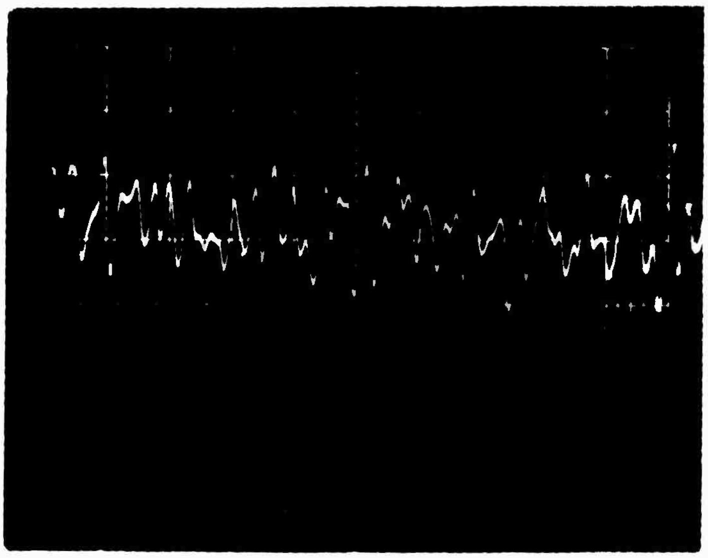
Phase $\phi_{1,2}$ channel
Input level: -6 db
Vertical scale: 1.28 degrees/cm
Time scale: 50 ms/cm



Phase $\phi_{1,2}$ channel
Input level: +3 db
Vertical scale: 1.28 degrees/cm
Time scale: 50 ms/cm

Measurement of variation in phase difference due to noise and receiver instabilities—continued

System operating frequency: **437.2932 MHz**

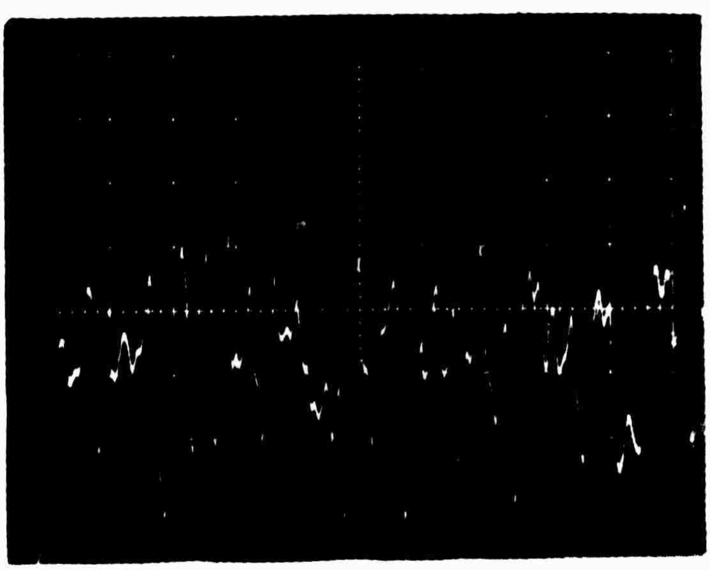


Differential phase measuring channel

Input level: -10 db

Vertical scale: 4.1 degrees/cm

Time scale: 50 ms/cm



Phase $\phi_{1,2}$ channel

Input level: -10 db

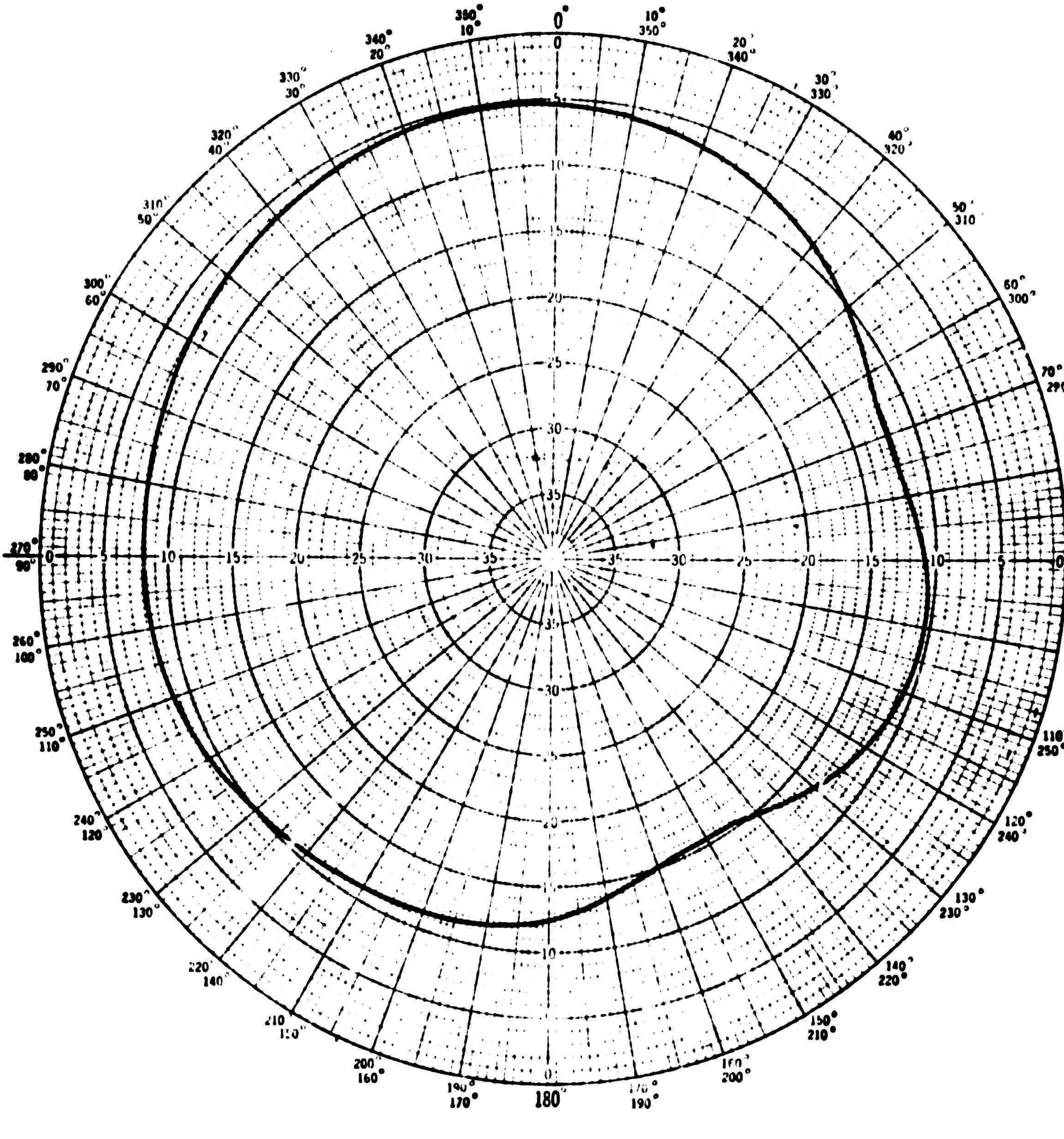
Vertical scale: 3.34 degrees/cm

Time scale: 50 ms/cm

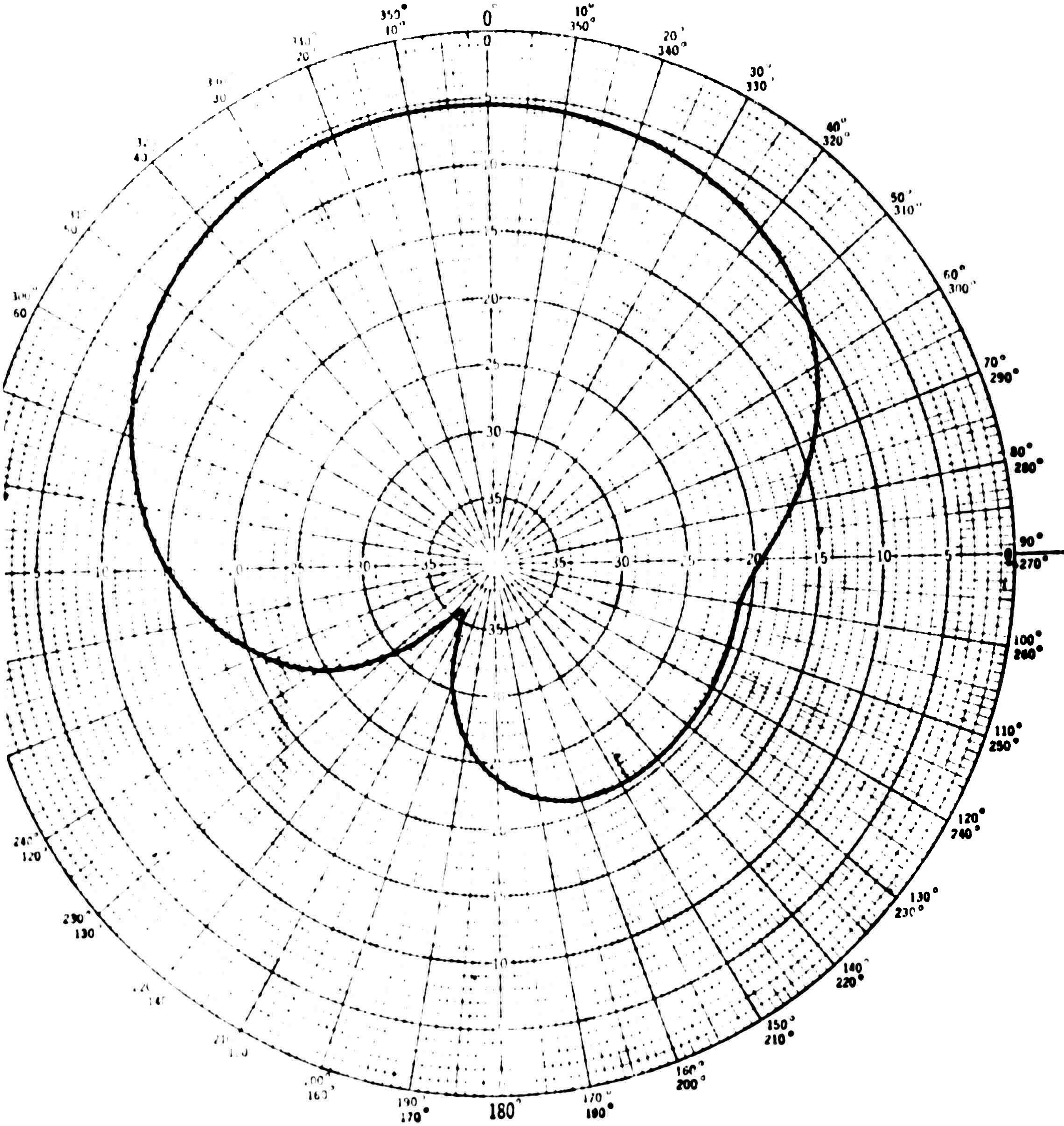
APPENDIX F

ANTENNA PATTERN MEASUREMENTS

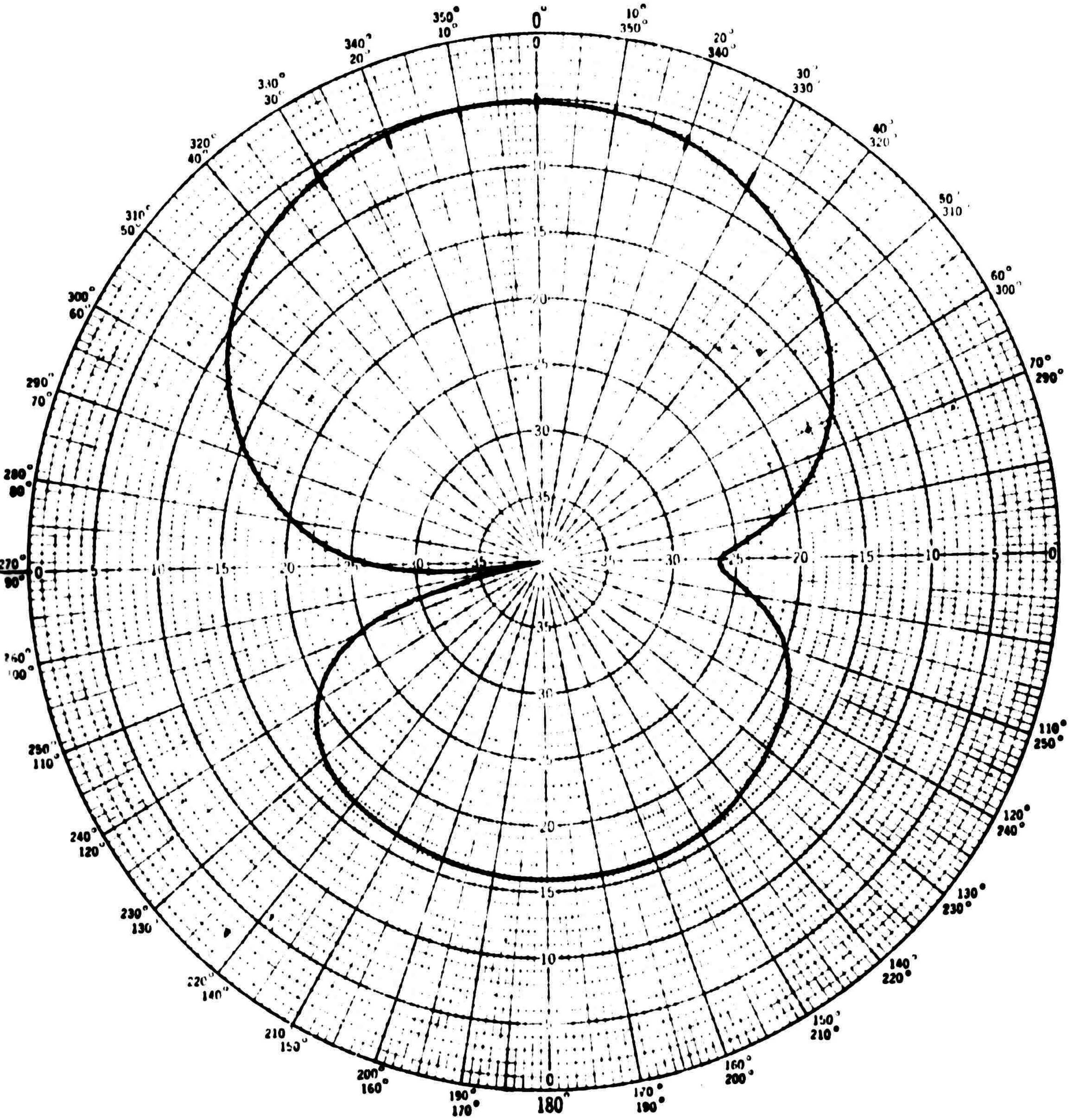
Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Horizontal Linear
Frequency: 145 MHz
Pattern: Yaw Plane, Port 3 (RHC)



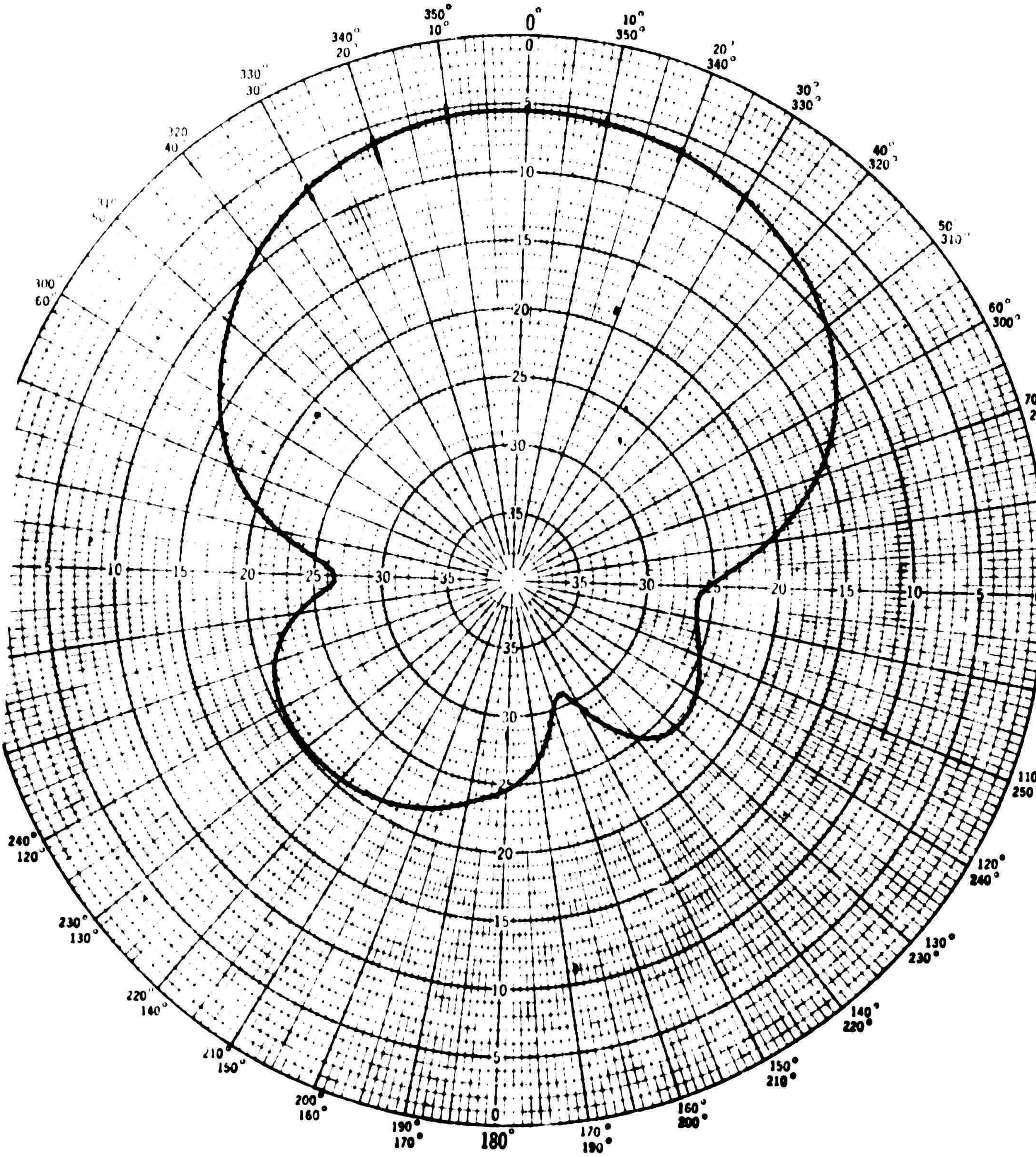
Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Linear Vertical
Frequency: 145 MHz
Pattern: Pitch Plane, Port 3 (RHC)



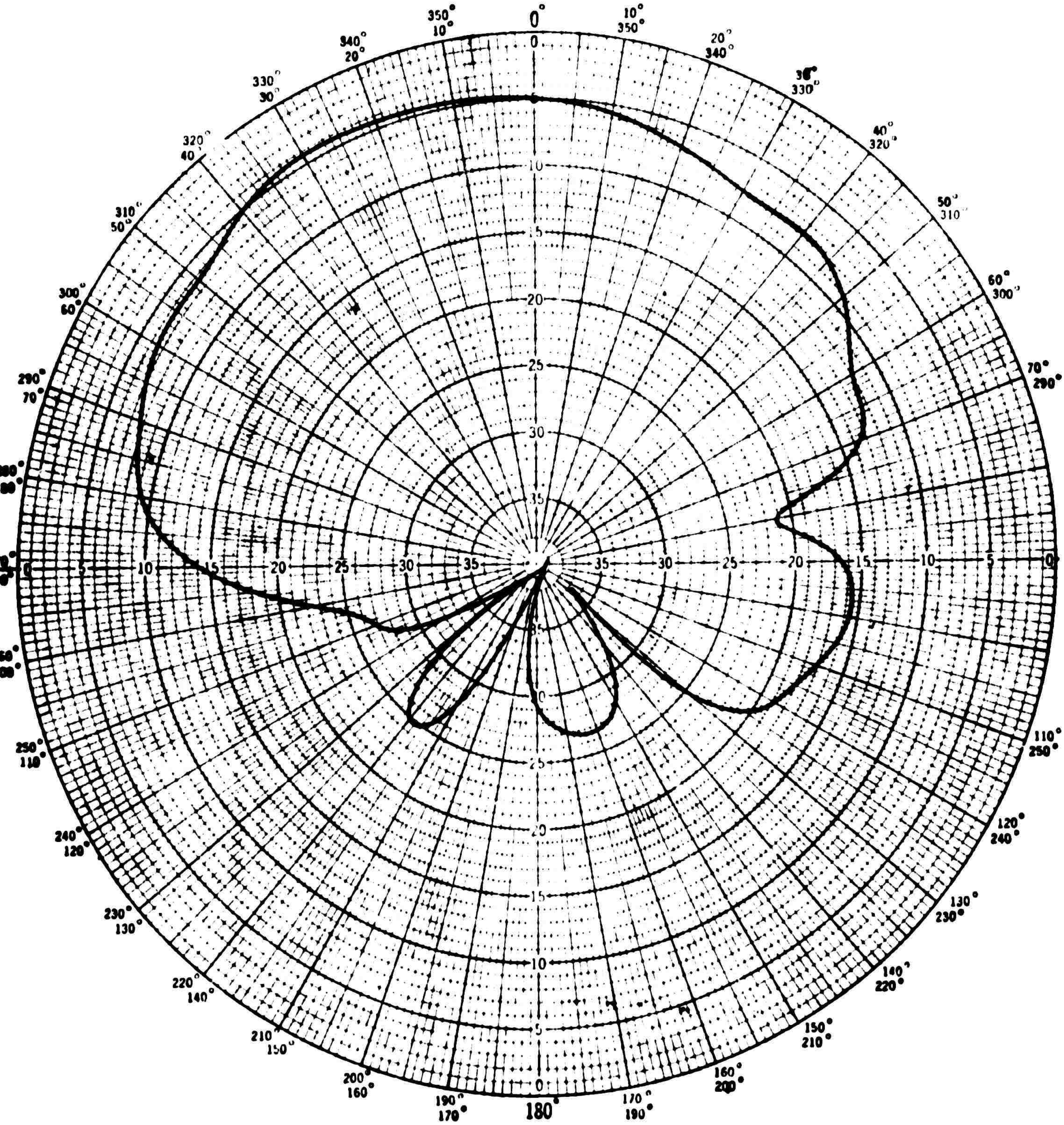
Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Horizontal Linear
Frequency: 145 MHz
Pattern: Pitch Plane, Port 3 (RHC)



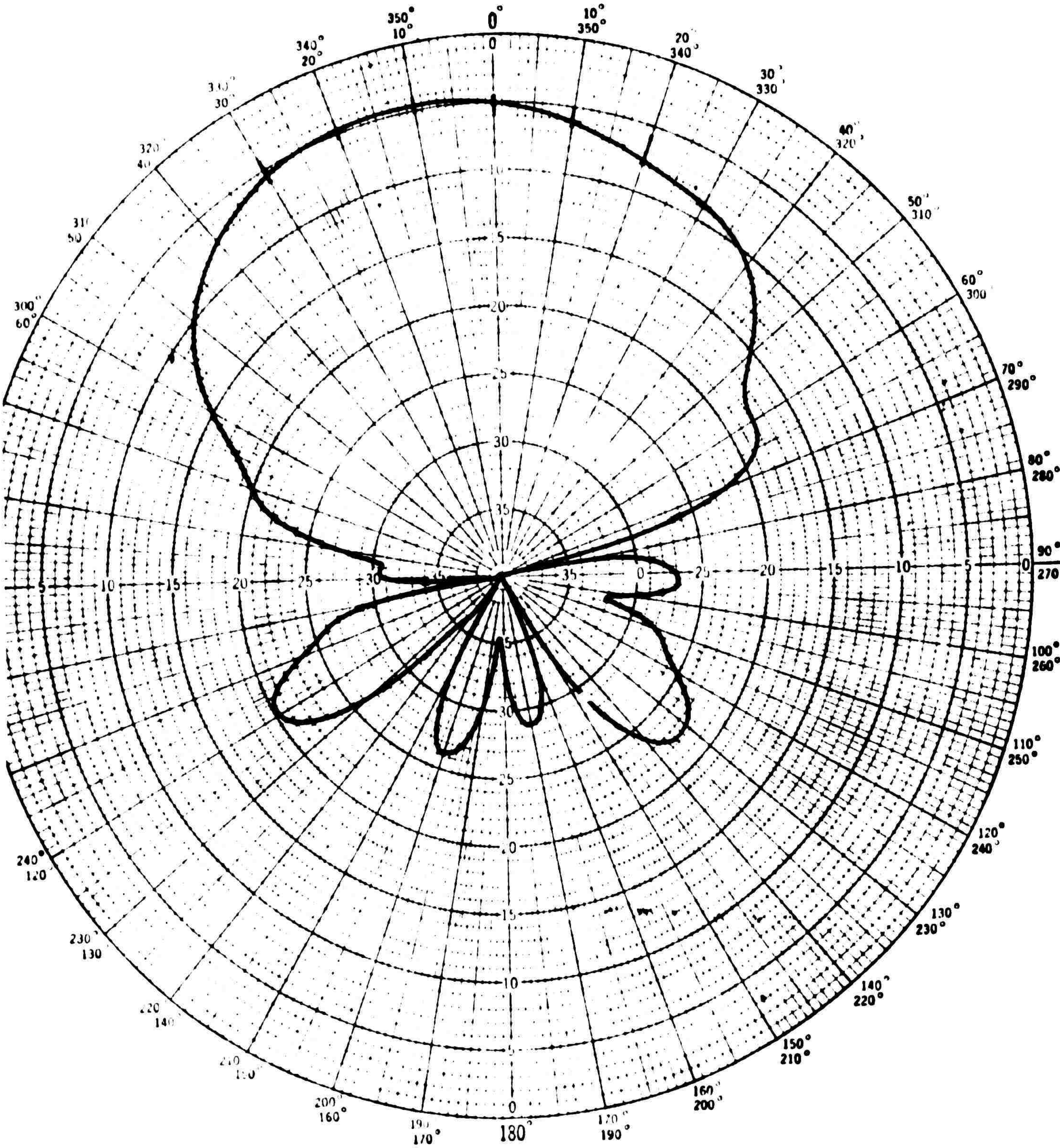
Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Vertical Linear
Frequency: 145 MHz
Pattern: Yaw Plane, Port 3 (RHC)



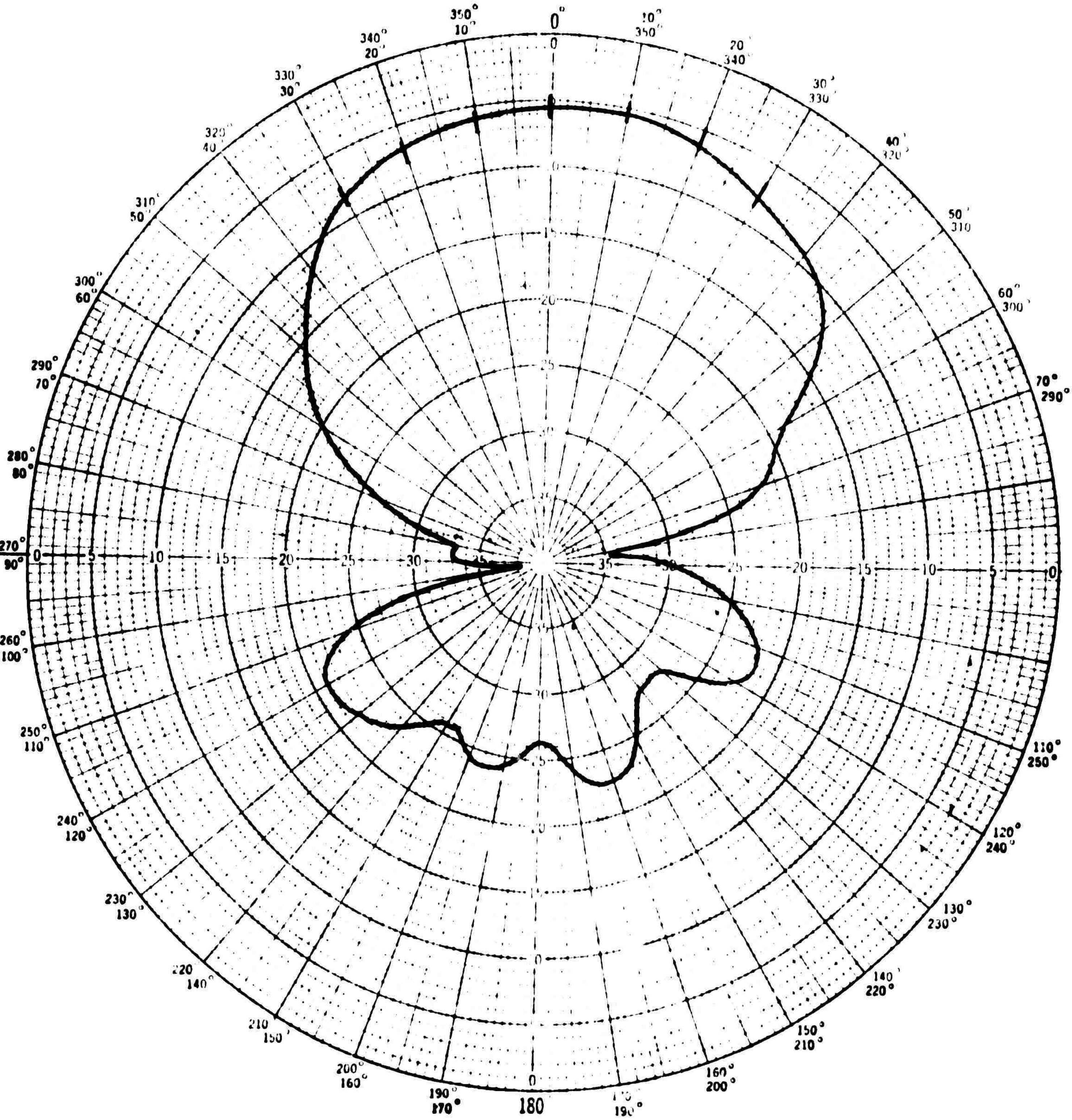
Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Vertical Linear
Frequency: 437 MHz
Pattern: Pitch Plane, Port 3 (RHC)



Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Horizontal Linear
Frequency: 437 MHz
Pattern: Pitch Plane, Port 3 (RHC)



Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Vertical Linear
Frequency: 437 MHz
Pattern: Yaw Plane, Port 3 (RHC)



Antenna Model No.: ADVANT 5-057001A
Type: Log Periodic
Transmitter Polarization: Horizontal Linear
Frequency: 437 MHz
Pattern: Yaw Plane, Port 3 (RHC)